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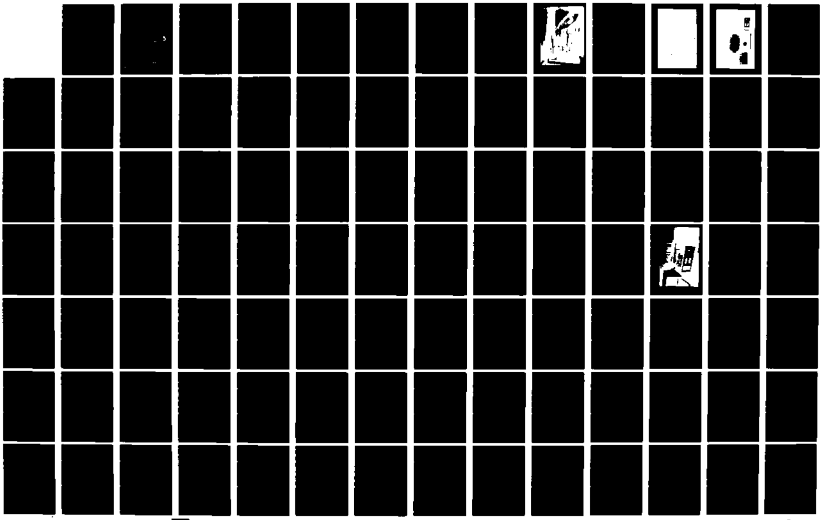

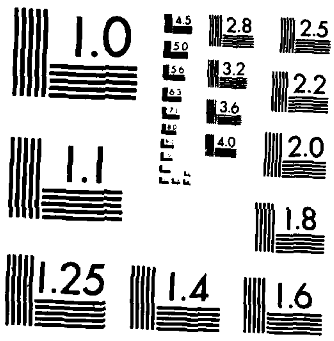

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ANTENNA DIGITAL CONTROL FOR THE
DIRECTED MIRROR ANTENNA RADAR (DMAR)
(CONTRACT N00173-80-C-0425)

THE NAVTROL COMPANY
9204 MARKVILLE DRIVE
DALLAS, TEXAS 75243

FEBRUARY 15, 1983
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PREPARED FOR:
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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont.)

SECTION 1.
INTRODUCTION

This report defines the development of the antenna control system for the Naval Research Laboratory's Directed Mirror Antenna Radar (DMAR). Figure 1-1 is a photograph of the Radar System antenna. As illustrated there, the reflector dish is a flat mirrored disc, six feet in diameter, supported by a gimballed structure providing rotational motion in 2 axes. The gimballed structure is such that the 2 axes of rotation intersect at a point which is diametrically centered on the "dish" but is located just behind it. Encoders and tachometers located on each of the gimbals measure angle and angular rate. Motion of the mirror is provided by 4 hydraulically driven pistons whose construction is such as to provide maximum linearization of the actuation with respect to motion of the dish. Wide dynamic response is a requirement for the system.

The radar feed system, which provides appropriate beam shaping in directing the beam towards the mirror, remains stationary eliminating the need for rotating joints. Control of the radar's beams direction is provided for by motion of the mirrored surface.

For controlling the NRL developed antenna, the All Digital Controller developed by Navtrol was utilized. The A l Digital Controller is a fast, programmable digital machine dedicated to servo control of multi axis or highly complex systems. It's

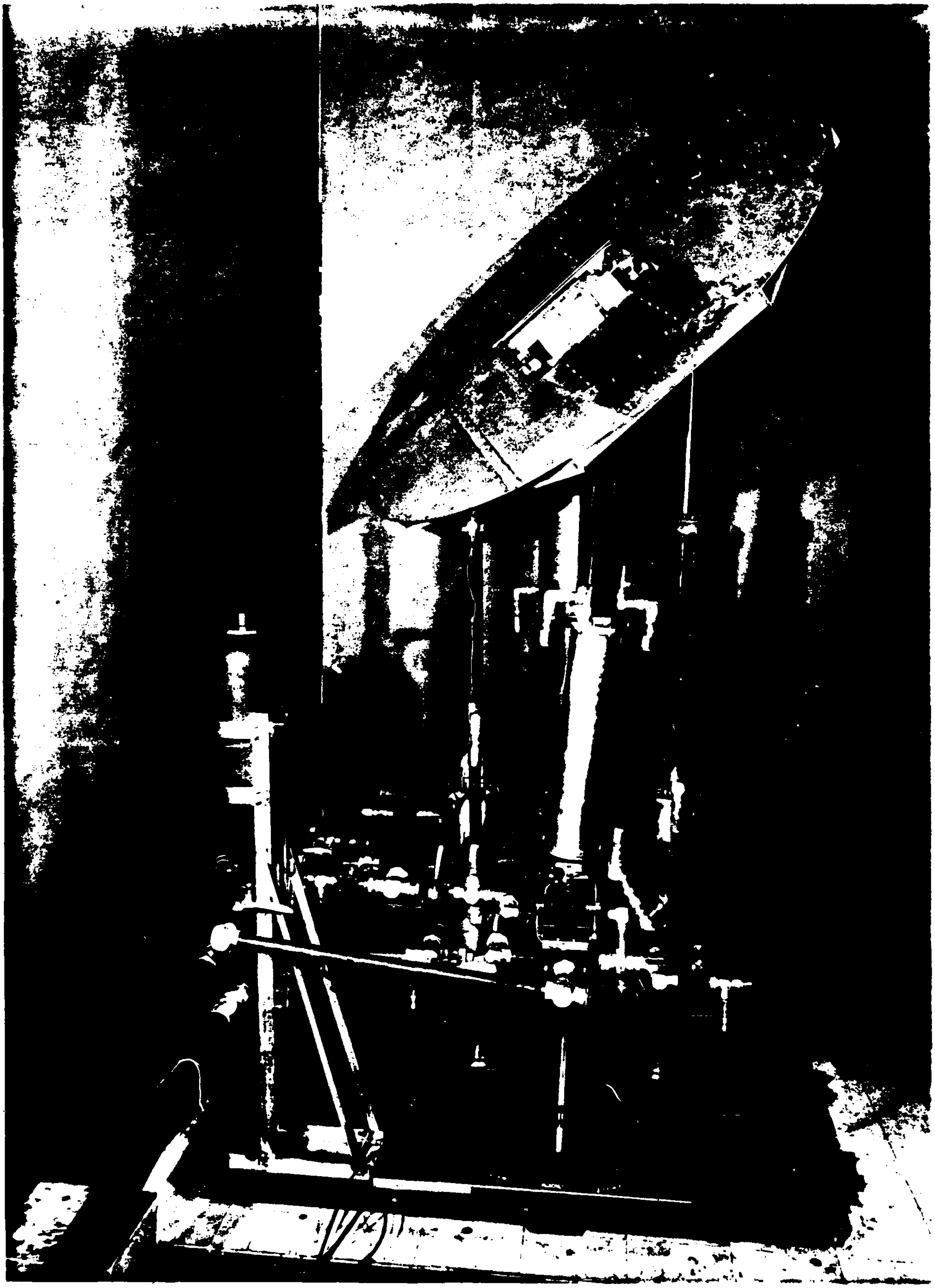


FIGURE 1-1: Photograph of the Directed Mirror Antenna Radar (DMAR) Antenna

heart is a digital processor designed specifically for closed loop control. High speed, special architecture and special commands set it far above micro processors or mini computers for control applications. The Digital Controller processor is general purpose and capable of performing many different and varied tasks. It is particularly adaptable to highly repetitive tasks requiring fast processing.

The computational capabilities required to control the antenna are encompassed in the components shown in Figure 1-2. The card cage is capable of holding 6 boards. The four boards included in NRL's system, shown left to right, are the RAM Memory Board, the Serial IO Board, the Processor Board and the Parallel Interface Board (above the other 3). Minimum configuration is 3 boards, deleting the Parallel Interface board. Two identical interface units, each 2" x 4.5" x 6.5", provided the required interfaces with the hydraulic system, the encoder and tachometer. These interface units were interconnected to the processor unit through a high speed, serial interface consisting of 4 differential lines.

Figure 1-3 is a photograph of the "Servo Development System," providing not only the capacity for software development but also a curve plotting graphics capability both on the CRT display and printout. Error signals, angles, torque output signals, etc. can be graphically displayed illustrating the systems time response to steps, sine wave inputs, etc. This capability is essential for efficient development of complex closed loop control systems.

FIGURE 1-2: The Digital Controller Processor Unit

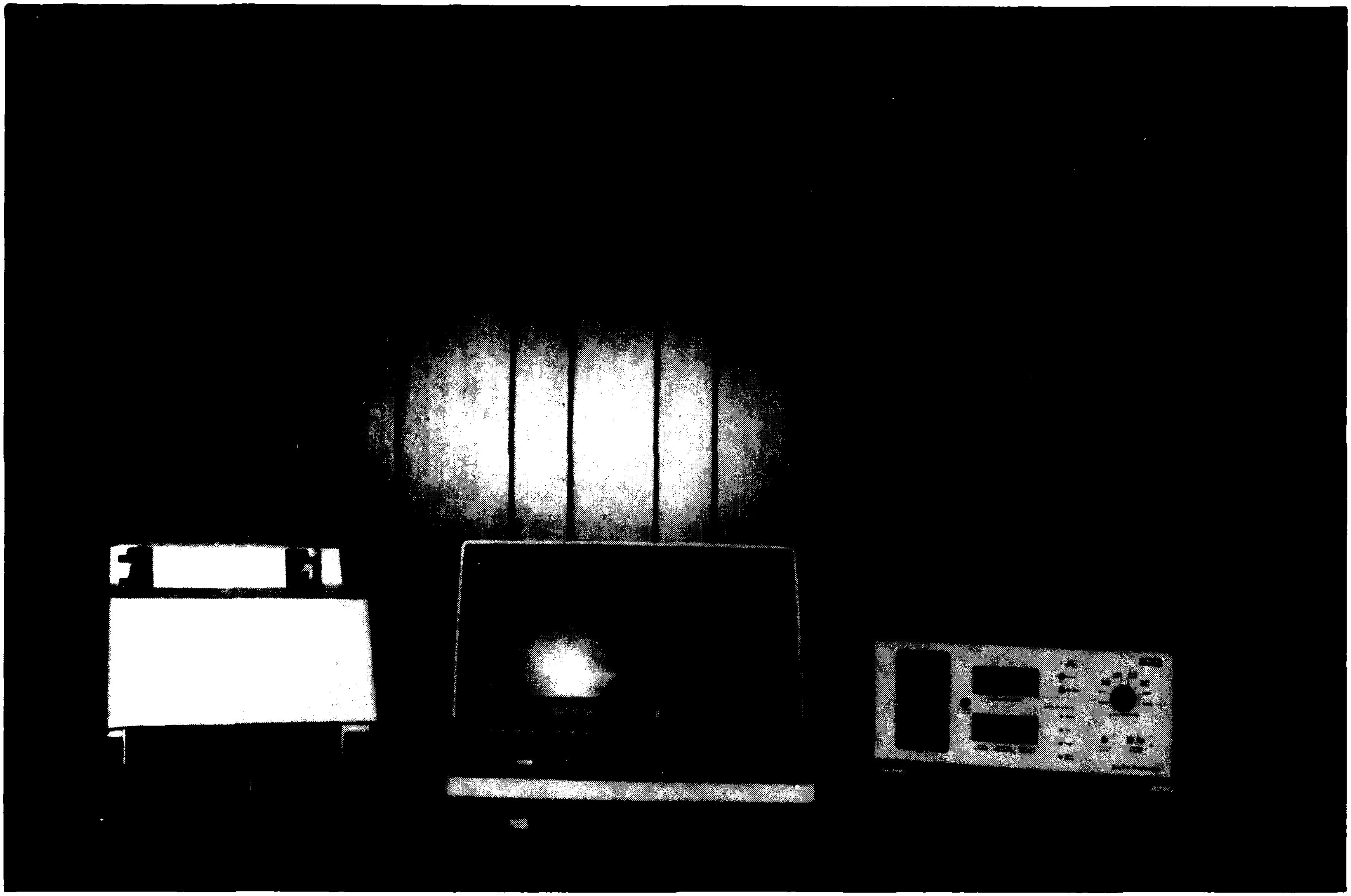


FIGURE 1-3: All Digital Controller Servo Development System

In the NRL System, the processor unit is included within the Main Digital Controller unit, shown on the right hand side of Figure 1-3. Also included within this unit is a Z80 based micro computer, referred to as the Front Panel Computer, which provides the interface capability between operator and control system. It contains the intelligence for the just described graphical presentation of data. The Main Digital Controller Unit is capable of operating independently of the CRT terminal or keyboard, containing on the front panel its own displays and input keyboard. This keyboard can provide complete control of the system once development is complete and program software is contained in PROMS. At present, NRL software is contained in diskettes and use of the CRT is a requirement.

The control system provides the capability for storing the direction and directional rate for 8 moving "targets". The operator can command the system to point the beam at any target, or scan about any target using one of two scan patterns. One pattern provides orthogonal sine waves which can be phased to provide a circular or eliptical pattern about the target. A "box" scan capability is also provided, where the box side lengths and the scan velocity can be varied. By setting the vertical lengths to almost zero a pure horizontal sector scan results. A vertical sector scan, is also possible. Scanning motion can be commanded either of the gimbals directly or of the beam.

This work was accomplished under NRL Contract N00173-80-C-

Ø425. The contract was a result of an unsolicited proposal in turn resulting from the Small Business Vendor's Day and Open House sponsored by ONR and NRL on 1 November, 1979. During that conference it was established in conversations between Dr. R.J. Brown of the Navtrol Company and Dr. C.L. Temes of the NRL Radar System Group that a radar system undergoing development at NRL required a control system similar in configuration to one being developed for NASA by the Navtrol Company. From that initial conversation additional meetings and discussions were held finally resulting in an unsolicited proposal, which in turn resulted in this development contract.

The radar antenna and the control system for the radar antenna were developed in parallel. In developing the control system, Navtrol required both assistance and direction from NRL Engineers. Both were provided with enthusiasm and good humor a fact that is greatly appreciated by Navtrol. The NRL engineers who worked most closely with Navtrol on this program are Dean Howard, Dave Cross and Jim Titus.

SECTION 2
FUNCTIONAL APPROACH

2.1 BASIC APPROACH

In the Introduction a picture of the Radar System Antenna was provided in Figure 1-1. Figure 2.1-1 provides an engineering sketch of the DMAR System. Radar energy is directed up through the center of the flat radar reflector directed onto the inside top of the radome. There the beam is reflected back toward the flat mirrored surface and directed out through the radome to provide the required surveilance. The radar feed system, consisting of the feed and the shaped radome reflector, provides appropriate beam shaping in directing the beam toward the mirror. The radar feed system remains stationery eliminating the need for rotating joints. Control of the radar beam's direction is provided for by motion of the flat mirrored surface. This flat disk is supported by a gimballed structure providing rotational motion in 2 axes. Encoders and tachometers located on each of the gimbals measure angle and angular rate. Motion of the mirror is provided by 4 hydraulically driven pistons. This construction is such as to provide maximum linearization of the actuation with respect to rotation of the dish. Wide dynamic response is a requirement for the system.

As discussed further in the Introduction, digital control through use of the All Digital Controller developed by Navtrol was selected because of the versatility and flexibility afforded. The heart of this system is a digital processor designed specifically for closed loop control. It is within this

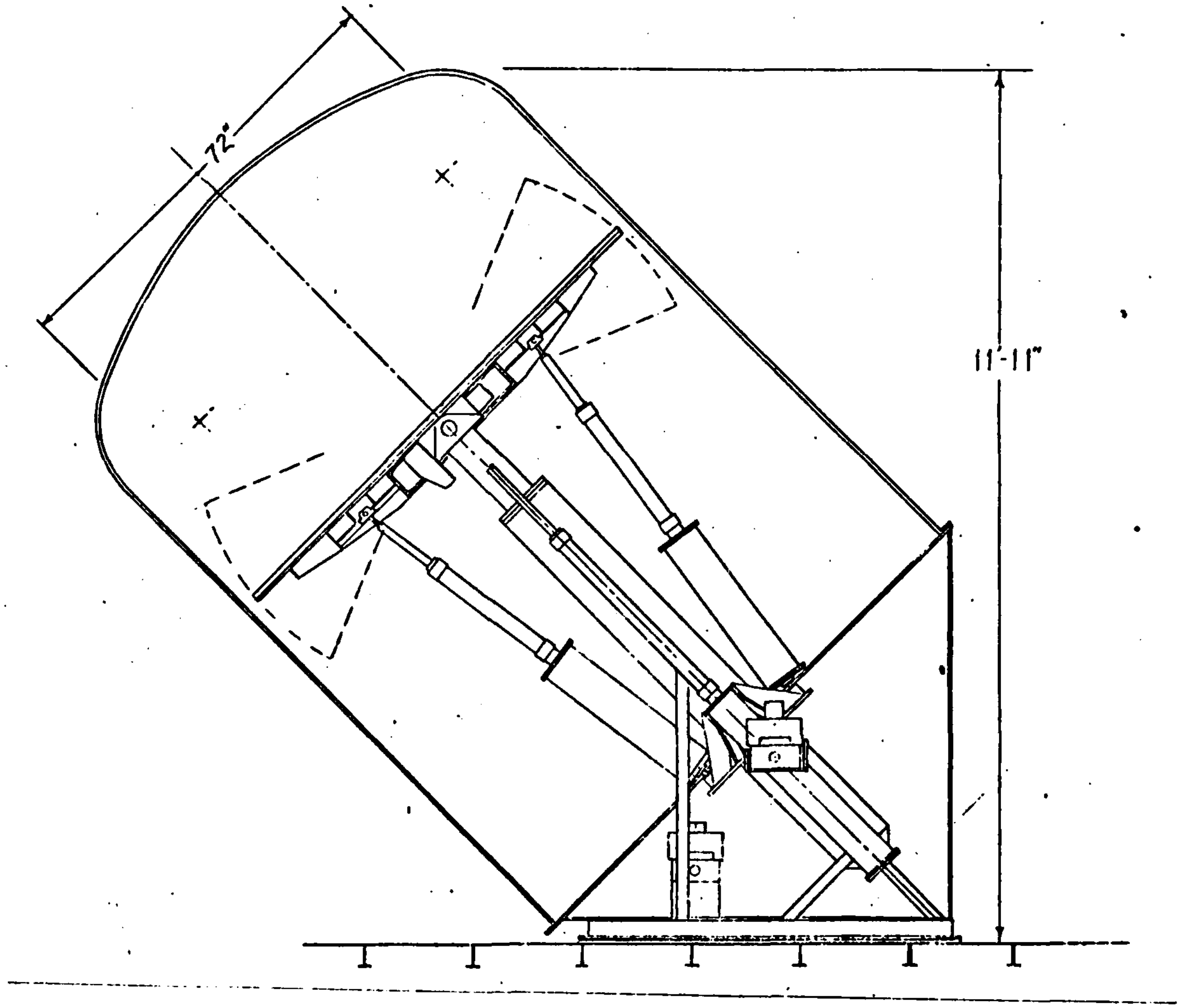


FIGURE 2.1-1: Engineering Sketch of the DMAR System

processor that most of the functions discussed in the following sections are performed. However, the digital system must interface with the hydraulic control system and this is accomplished through use of 2 special interface units containing A/D's and D/A's. The D/A's provides the control signal which are passed through special amplifiers to the hydraulic servo valves. Measurements are made on each of the gimbal angles using 16 bit absolute encoders. Measurements are also made of gimbal velocity, through use of tachometers, and hydraulic system differential pressure. Figure 2.1-2 provides an indication of the components of the control system.

The basic functional approach for controlling NRL's Directed Mirror Antenna Radar (DMAR) is illustrated on Figure 2.1-3. To provide for easy transmittal of data pertaining to target direction from one system to another, and even from one ship to another it was decided that the pointing vector to the targets would be defined with respect to the inertial reference system. Included was the definition of and programming into software of transformations for ships motion and antenna alignment, tasks that possibley could have been delayed until later development. However, these transformations were straightforward and a large amount of engineering time was not required. These transformations provide easy adjustments for orientation of the antenna which was different in the laboratory and at the Chesapeake Bay facility. Their value have already been proven in laboratory demonstrations. In addition, the inclusion of these transformations provided a better example of the

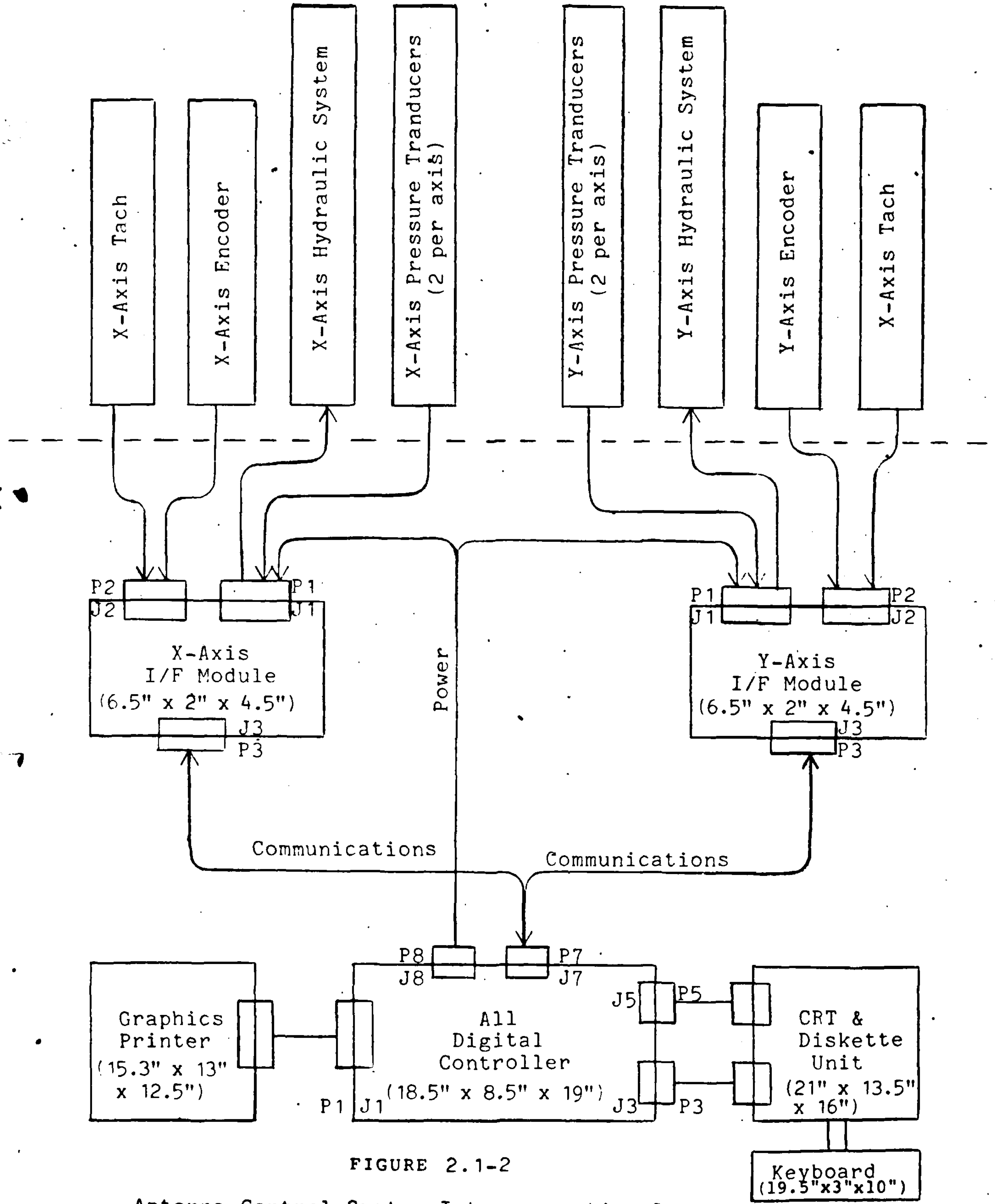


FIGURE 2.1-2

Antenna Control System Interconnection Diagram

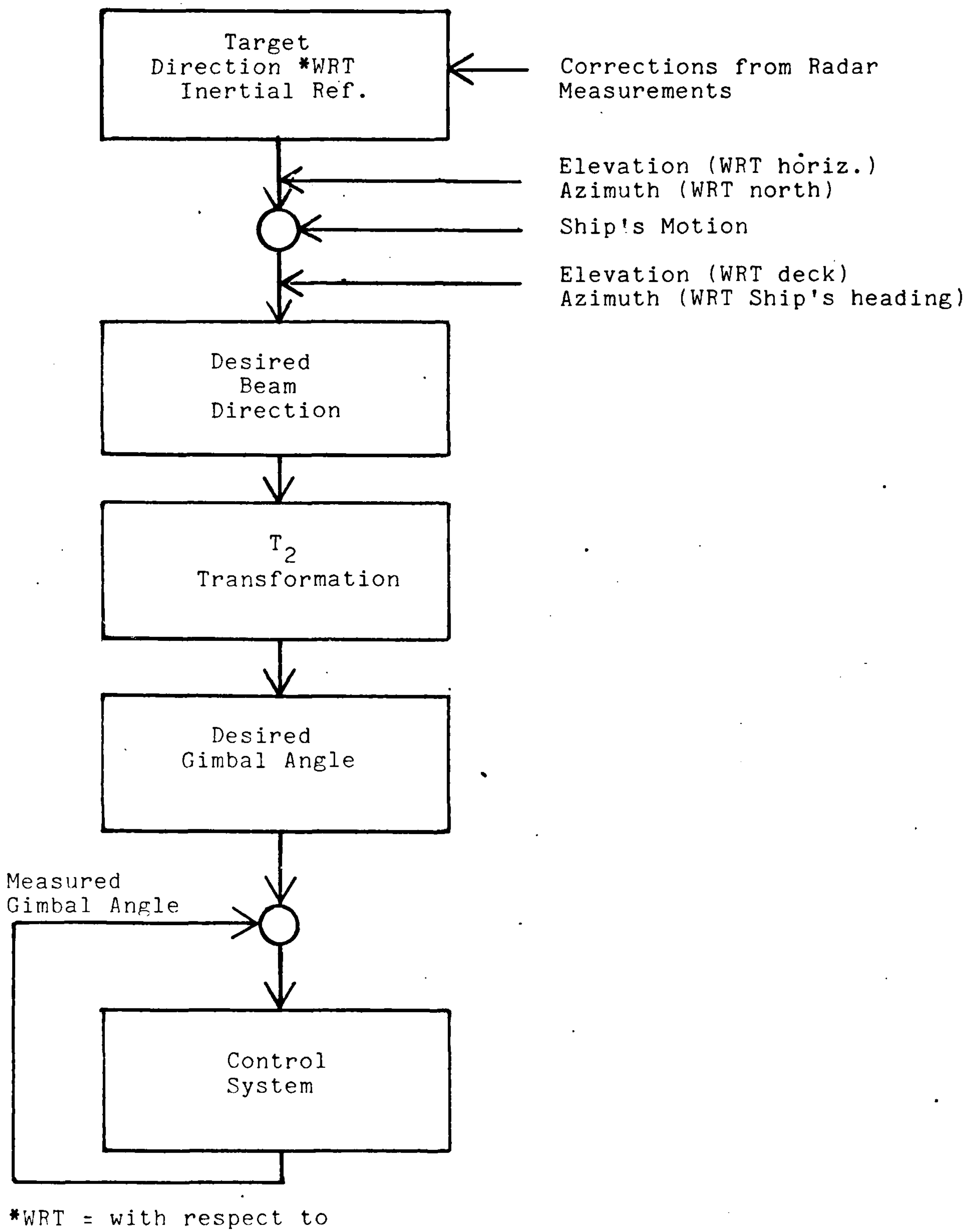


FIGURE 2.1-3

Basic Control Approach

computations involved in controlling an antenna of the type envisioned.

Defining algorithms to calculate gimbal angles and rates required to point the beam at any moving target within the antenna coverage was a much greater task than defining the ships and antenna alignment transformation and it could not be delayed. The complexity comes about because the "half angle" relationship between gimbal angle and beam rotations, which is simple enough in one plane, becomes complex for out of plane situations. For this "transformation," Navtrol derived an approach which side steps direct computation of gimbal angles and greatly simplifies the computational complexity. This approach, which is believed to be novel, is described in Section 2.3.

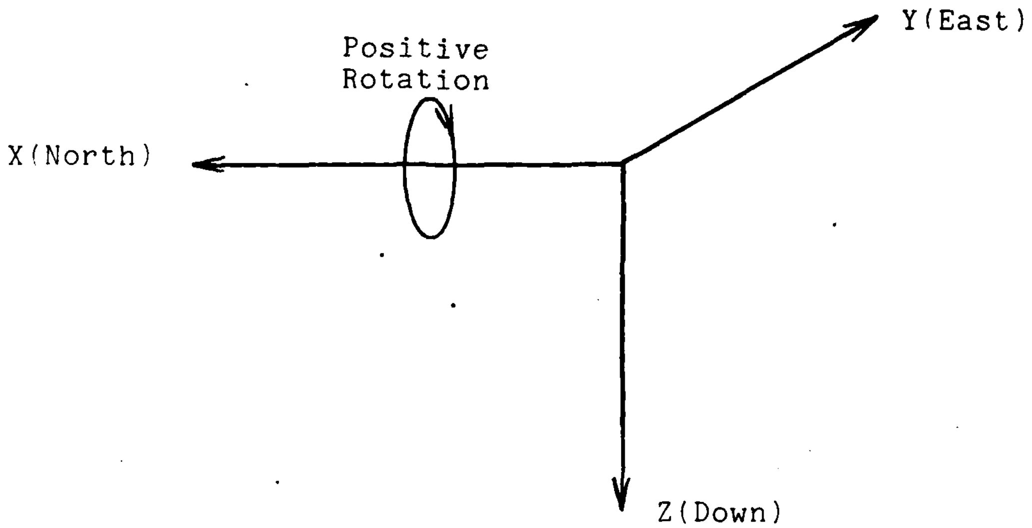
As indicated on Figure 2.1-1, after the desired gimbal angles are derived they are compared with the measured gimbal angles and the antenna controlled in such a way as to force the measured angles to equal the desired gimbal angles.

2.2 COORDINATE REFERENCE SYSTEMS

Figure 2.2-1 illustrates the basic inertial reference coordinate system. As indicated, the X axis points north, the Y axis east and the Z axis down. This is a right handed coordinate system which conforms to the standard which although not absolute is generally used aboard ships and airplanes. Positive rotation is defined by the right hand rule where the thumb points in the direction of the positive vector and the curled fingers indicate the direction of positive rotation. The direction on positive roll is indicated on Figure 2.2-1. The pointing of the Z axis

FIGURE 2.2-1:

Inertial Reference Coordinate System



Inertial Axes:

X = North

Y = East

Z = Down

Inertial Rotations:

ϕ = rotation about X = roll

Θ = rotation about Y = pitch

ψ = rotation about Z = azimuth

down may seem strange but corresponds to the standard. Note that rotation about Z provides a positive rotation of 90 degrees in going from north to east, in correspondence with accepted standards. Also, the positive rotation about the Y axis provides a pitch up angle, positive above the horizon.

Figure 2.2-2 provides additional details on the transformation performed by the Navtrol system in order to get the desired gimballed angles and gimbal rates. Table 2.2-1 provides mathmatical expressions for the transformations. Note that on this table the transformation T_T is the inertial transformation of Figure 2.2-2. Direction to a particular target is defined by the azimuth angle and the elevation or pitch angle in the inertial reference frome. For rapidly moving targets angular rates for the target also can be inserted. Since scanning is accomplished by causing the beam to track a pseudo target, very high rates can be encountered. The two target angles define a coordinate transformation through which a unit vector is passed, in turn defining the target vector in inertial reference coordinates, designated X_T in the diagram. Angular rates, represented as vectors, are transformed separately from the direction vector.

The target direction and angular velocity vectors are next passed through the ship's transformation. The ship can be oriented in any direction by placing the appropriate constants in Data Memory. As delivered to NRL, it is assumed in the software that the ships orientation in each axis is 0 degrees. This implies that the ship is heading north with its decks

TABLE 2.2-1: Transformations Required

A. Tracking Equations:

1) $\bar{\Theta}_a = \bar{G}_{1n}\left\{\bar{x}_{os} + \left[\bar{T}_a \cdot \bar{T}_s\right]\bar{X}_T\right\}$

2) $\dot{\bar{\Theta}}_a = \bar{G}_{dn}\left\{\bar{T}_a\left[\bar{D}_s \cdot \bar{X}_T + \bar{T}_s \cdot \dot{\bar{X}}_T\right]\right\}$

3) $\dot{\bar{L}}_a = \bar{G}_{2n}\left\{\dot{\bar{\Theta}}_a\right\}$

B. Additional Scanning Equations:

4) $\bar{X}_T = \bar{T}_T \bar{U}_x$

5) $\dot{\bar{X}}_T = \bar{D}_T \cdot \bar{U}_x$

where:

$\bar{X}_T$ = Target Coordinate Vector, x = north, y = east and z = down.

$\bar{T}_s$ = Transformation Matrix, Ship's Motion

$\bar{T}_a$ = Antenna Alignment Transformation Matrix.

$\bar{X}_{os}$ = Offset Vector of Antenna from Ship's Fire Control.

$\bar{G}_{1n}$ = Non-linear conversion to desired Gimbal Angles.

$\bar{\Theta}_a$ = Desired Gimbal Angles.

$\dot{\bar{X}}_T$ = Time Derivative of Target Coordinate Vector.

$\bar{D}_s$ = Time Derivation of Matrix $\bar{T}_s$.

$\bar{G}_{dn}$ = Non-linear Conversion to Desired Gimbal Rates.

$\dot{\bar{\Theta}}_a$ = Desired Gimbal Rates

$\bar{G}_{2n}$ = Non-linear Conversion to Desired Average Piston Rates.

$\dot{\bar{L}}_a$ = Desired Average Piston Rates

$\bar{U}_x$ = Unity Vector in x (north, horizontal) Direction.

$\bar{T}_T$ = Transformation Matrix to get Target Coordinates.

$\bar{D}_T$ = Time Derivative of $\bar{T}_T$

$\dot{\bar{X}}_T$ = Time Derivative of $\bar{X}_T$

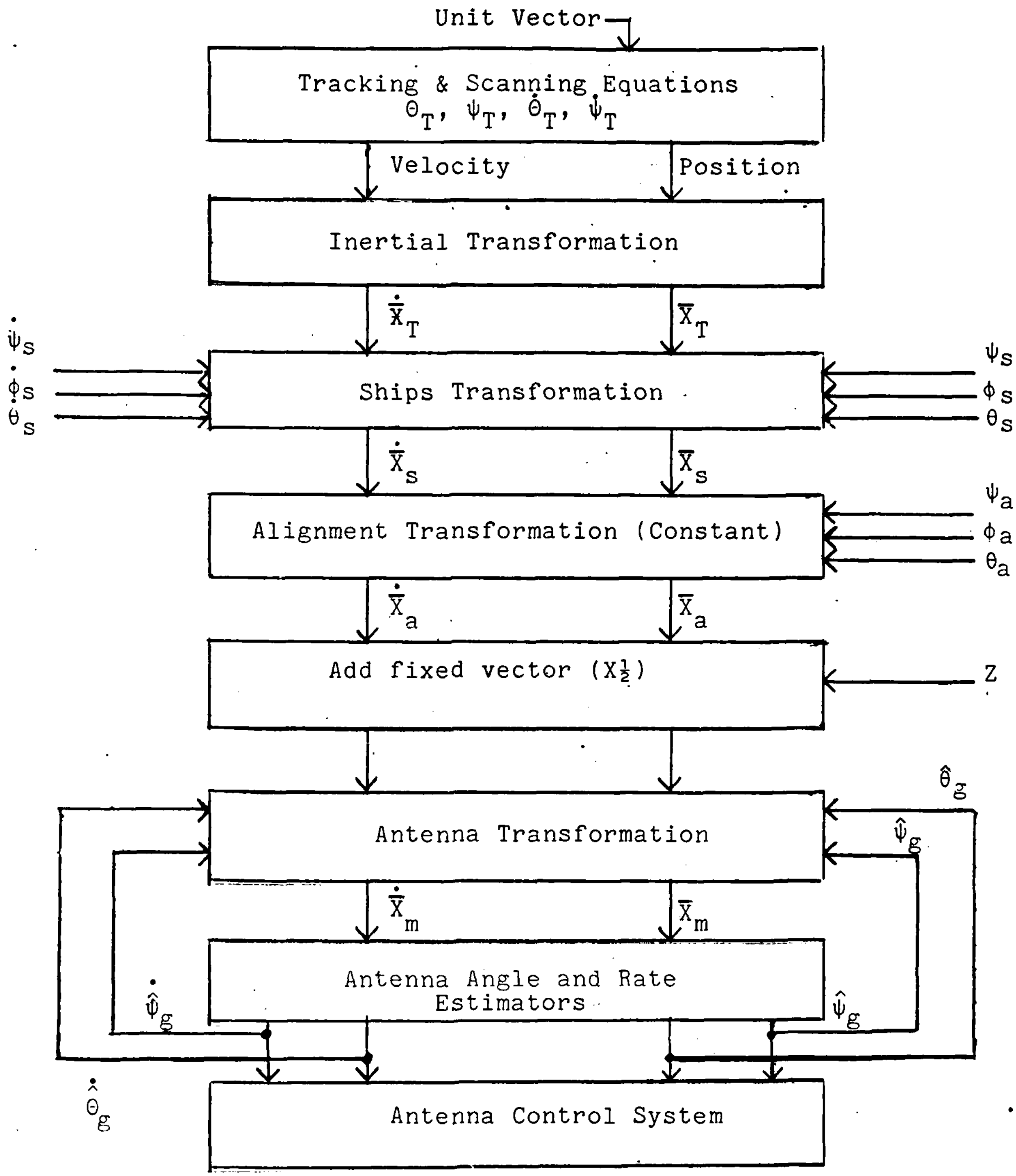


FIGURE 2.2-2: Control Definition and Transformations

TABLE 2.2-2: Translation Table for Angular Conversion From Decimal to Hexidecimal

Ship's Tranformation Angles	Location
PSIS, Azimuth	0167
THETAS, Pitch	0168
PHIS, Roll	0169

Angle Magnitude Degrees	Plus Angle Hex Number	Minus Angle Hex Number
0.00	0000	0000
0.0055	0001	FFFF
0.011	0002	FFFE
0.022	0004	FFFC
0.044	0008	FFF8
0.088	0010	FFF0
0.18	0020	FFE0
0.35	0040	FFC0
0.70	0080	FF80
1.41	0100	FF00
2.81	0200	FE00
5.63	0400	FC00
11.25	0800	F800
22.5	1000	F000
45.0	2000	E000
90.0	4000	C000

horizontal. Rotation of the ships about the azimuth angle PSIS, provides an easy means for correction of azimuth for antenna coverage. Table 2.2-2 provides the location in Data Memory of the 3 ship's transformation angles and also a translation table for defining the hexidecimal number from the desired decimal angle. This hex number can be inserted using one of Navtrol's Monitor programs, either PMONITOR or SMONITOR.

In transforming from one coordinate system to another, Euler angle rotations must be made in the proper order about each of the axes. In going from the ship to the inertial reference frame the order is X, Y and Z. In going from the inertial to the ships reference frame the rotation is Z, Y and X, in that order. Since Z is the first rotation, the rotation is made about vertical, corresponding to the standard definition of azimuth. The next rotation is about the Y axis so that pitch corresponds to the angle above the horizon, again corresponding to the standard. The last rotation is roll which is about the X axis which has a fixed alignment through the ships bow. A program listing of NRL's system software is provided in Appendix A. Within the program, comment statements clearly define the Euler angle rotations which make up the coordinate transformations. These comments appeared just before the assembly level instructions which perform the actual operations.

An "antenna alignment" transformation is provided to permit software adjustment for mounting alignment of the antenna with respect to the ship. When installed at the Chesapeake Bay facility, the DMAR antenna is to be laid over so that the

"normal" to the antenna at null position is 30 to 45 degrees above the horizon. The alignment transformation allows this to be accounted for computationally. The alignment transformation is assumed to be fixed once the antenna is installed and the trigometric functions must be calculated externally and the resultant parameter values inserted in the appropriate memory locations. With zero angles in the "Antenna Alignment" transformation, resultng in an identity matrix, the orientation of the antenna is such that the positive X axis of the antenna, with no Y axis rotation, points toward the ship's bow, while the Y axis points directly starboard and the Z axis downward. This was the orientation of the antenna in the laboratory and in NRL's delivered software the alignment transformation was a identity matrix. Laying the antenna over should be relatively straight forward with a rotation made about the X (roll) axis. Table 2.2-3 provides the equations required to adjust or define the alignment transformation parameters. Also provided is the location in Data Memory of the parameters. By use of the memory monitor option of the Monitor program, the data at these locations can be readily changed. Rotations about all three axes can be accommodated, but as indicated on the table the rotations must be made in the proper order. That is, the rotation in azimuth must be made before the rotation in pitch and etc. Otherwise, the results will not be as expected.

Because the antenna is a mirror the antenna transformation is not a straightforward transformation of the vectors from the alignment transformation. For the target direction vector a fixed vector is added to it such that the combination defines the

TABLE 2.2-3:

Alignment Transformation Parameter Definition

Parameter	Relationship	Parameter Location (Hex)	MSB
A1(Ø)	= (CP)*(CA)	Ø2ØØ	.5
A1(1)	= (CP)*(SR)	Ø2Ø1	.5
A1(2)	= -(SP)	Ø2Ø2	.5
A2(Ø)	= -(CR)*(SA)+(SR)*(SP)*(CA)	Ø2Ø8	.5
A2(1)	= (CR)*(CA)+(SR)*(SP)*(SA)	Ø2Ø9	.5
A2(2)	= (SR)*(CP)	Ø2ØA	.5
A3(Ø)	= (SR)*(SA)+(CR)*(SP)*(CA)	Ø21Ø	.5
A3(1)	= -(SR)*(CA)+(CR)*(SP)*(SA)	Ø211	.5
A3(2)	= (CR)*(CP)	Ø212	.5

where;

CA = Cosine (Azimuth Angle)

SA = Sine (Azimuth Angle)

CP = Cosine (Pitch Angle)

SP = Sine (Pitch Angle)

CR = Cosine (Roll Angle)

SR = Sine (Roll Angle)

* = indicates multiplications

Angular rotations must be made in the order of Azimuth first, then Pitch and then Roll.

desired pointing direction. This is described further in the following section.

For the antenna gimbals, the X axis gimbal is defined as the gimbal nearest the antenna and is referred to in the software program as either Loop 1 or PHIG. The antenna Y axis gimbal is the gimbal nearest the base and is referred to within the software program as either Loop Ø or THETA. The X axis is capable of rotation about + or - 22.5 degrees while the Y axis is capable of rotating + and - 45 degrees.

To cause the antenna to perform a horizontal scan, requires that the antenna alignment frame be tilted over 45 degrees or more. A "target" which has zero degrees elevation and whose azimuth angle is varied according to the desired scan sector is then defined. By use of the transformations the required gimbal angles and appropriate controls are defined. The orientation with the X axis aligned fore and aft should permit the maximum amount of horizontal scanning motion broadside to the ship compared to other orientations.

As indicated above the direction to a target is defined as angle above the horizon, THETA, and an angle in azimuth with reference to north, PSI. The monitor program supplied by Navtrol to NRL permits placing as many as 8 targets using these angles to define the target direction. The antenna can be made to scan in either or both axes with reference to any of these 8 targets.

2.3 MIRROR "HALF ANGLE" TRANSFORMATIONS

Figure 2.2-2 indicated that a vector was added to the target vector in order to define the desired pointing direction. Figure

2.3-1 illustrates that relationship. The target vector is T1 and the unit vector added to it is a vector which points to the apparent source of RF energy and is designated U1. When the antenna is at the null position, the "source" vector lies along the negtive Z axis. Before adding the two vectors together they are divided by 2 to prevent overflow in the computer. The resultant of the addition is vector A which points in the desired direction for negative antenna Z axis or the "normal" to the mirror surface. The vector A is applied through a transformation whose angles are adjusted until the vector lies along the Z axis of the antenna, as desired. The angles required to achieve this are the desired gimbal angles.

Figure 2.3-2 provides a comparison of this "mirror" tracking to conventional tracking. In a conventional tracking system the target direction vectors are applied through the resolver chain. Pointing at the target is indicated by the target vector lying in the direction of the beam center. Pointing is accomplished by servo loops which control the antenna to null out the orthogonal vectors. This is illustrated in the A portion of Figure 2.3-2. Also shown is the mathematical representation which would be used within a computer.

The B portion of Figure 2.3-2 illustrates how the combination of the target vector and a vector pointing toward the source can be combined to create a new vector which defines the desired pointing for the antenna. In this example the multiplication by one half, a function of computer scaling, is not shown.

Angular rates are also adjusted by multiplying by one half

$\overline{U}_1$ = Unit Vector (toward source)

$\overline{U}_2 = \frac{1}{2}\overline{U}_1$

$\overline{T}_1$ = Target Vector

$\overline{T}_2 = \frac{1}{2}\overline{T}_1$

$\overline{A} = \overline{T}_2 + \overline{U}_2$

$\overline{A}$ = Antenna Pointing Direction

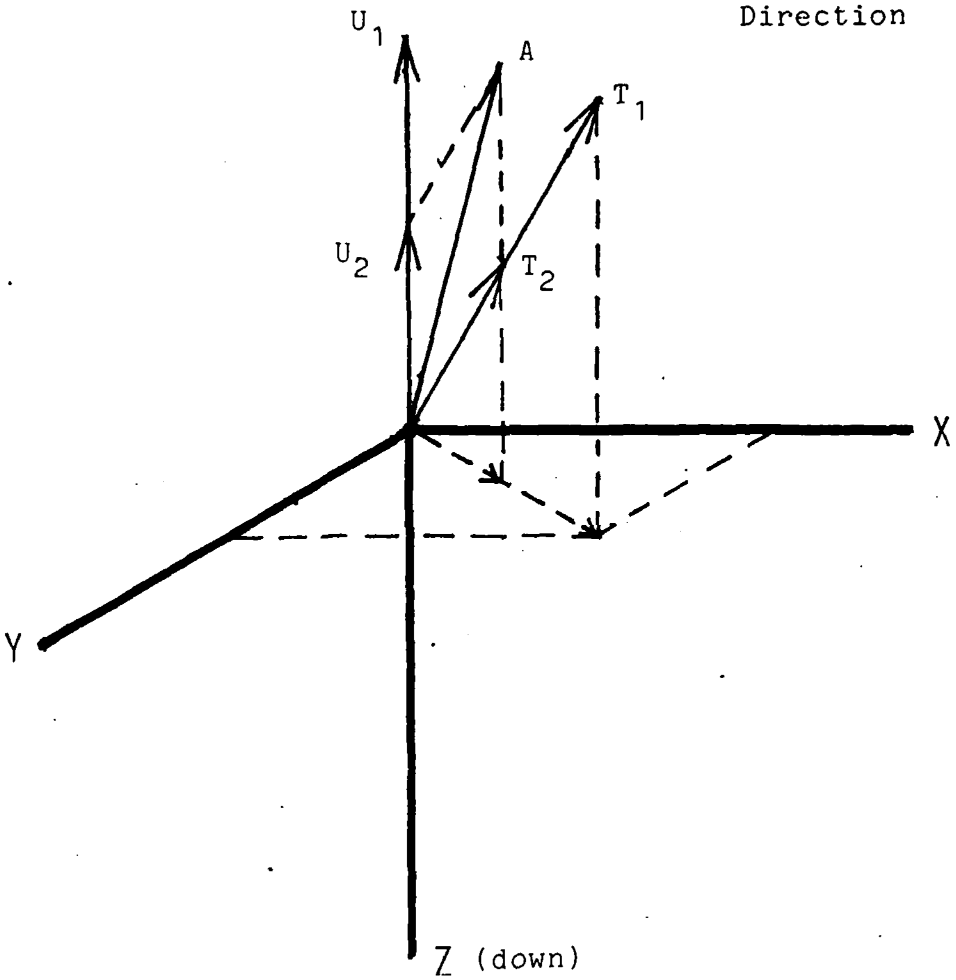


FIGURE 2.3-1

VECTOR RELATIONSHIP FOR MIRROR "HALF ANGLE" RELATIONSHIP

the rates for those axes which results in target velocity in the source-antenna-target plane. This can be accomplished by multiplying the rates about the two axes which are perpendicular to the vector which points to the source by one half. The rates about the source vector are not multiplied by one half. Appropriate transformation is then applied to these rates to obtain the appropriate gimbal rates. This approach does not result in rates which are correct about all axes. However, the rates are precisely correct about the two gimbal axes so that accurate tracking results. The resultant rate about the antennas Z axis is not correct but this does not affect keeping the beam on the target. The correctness of the angular and angular rate transformations was verified in extensive Fortran simulations.

2.4 GIMBAL CONTROL LOOPS

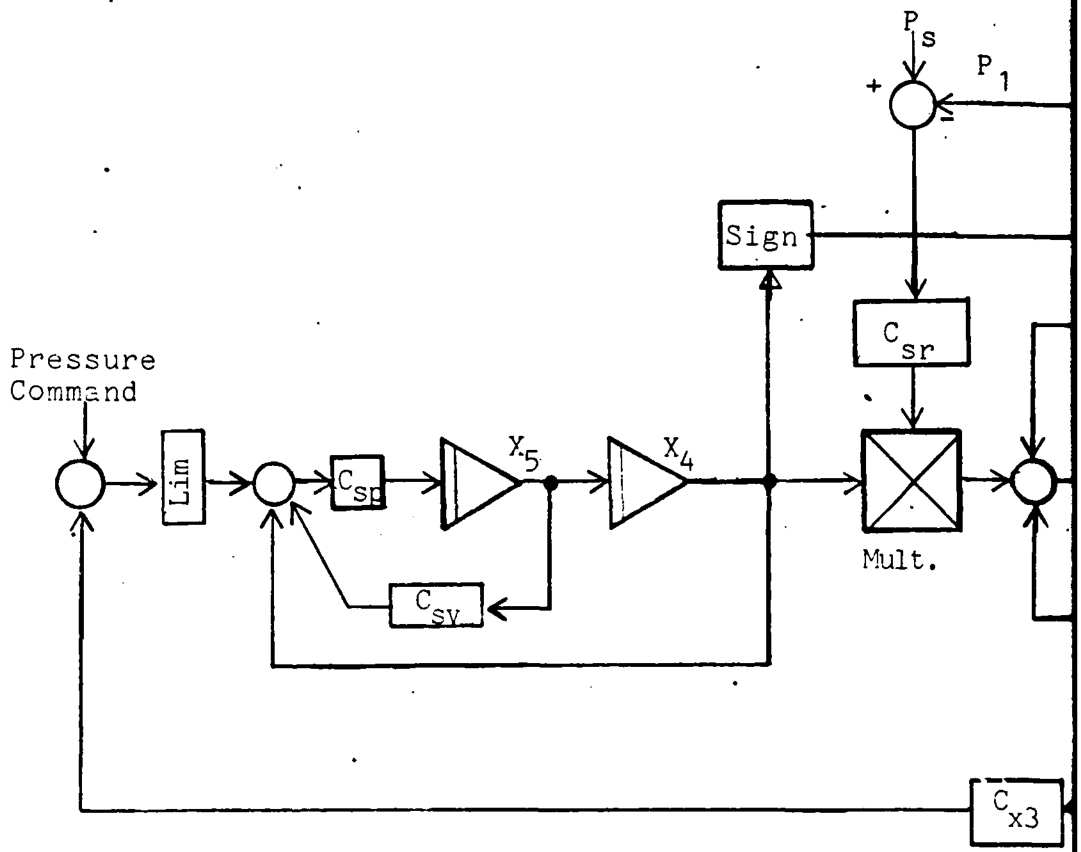
2.4.1 CONTROL SYSTEM FUNCTIONS

A picture of the radar system antenna was provided in Figure 1-1 in the Introduction. In that photograph many of the components of the hydraulic system are visible. As previously described, motion of the mirror is provided by 4 hydraulically driven pistons whose construction is such as to provide maximum linearization of the actuation with respect to motion of the dish. The distance from the center of the dish to the connection point of the pistons is 20 inches. Two pistons connected symmetrically on either side of an axes provides differential forces about each of the two axes. Pressure was measured at the base at each of the pistons. The two measurements for a particular axes were summed in such a way as to provide

a measurement of differential pressure. Angle and angular rate were measured at the gimballing connection of the dish to the mount. Angular measurement utilized a 16 bit absolute encoder while angular rate was measured by means of a tachometer. The servovalve for the hydraulic system was a Model DO79-210 manufactured by MOOG. This is a three stage servovalve using a Series A076 driver. Control of the servovalve was provided by a MOOG Model 82-30 DC servo amplifier. This combination provides a spool displacement proportional to the input voltage. This controls the hydraulic flow rate which in turn, after the initial transient has settled out, results in a piston rate proportional to the applied voltage.

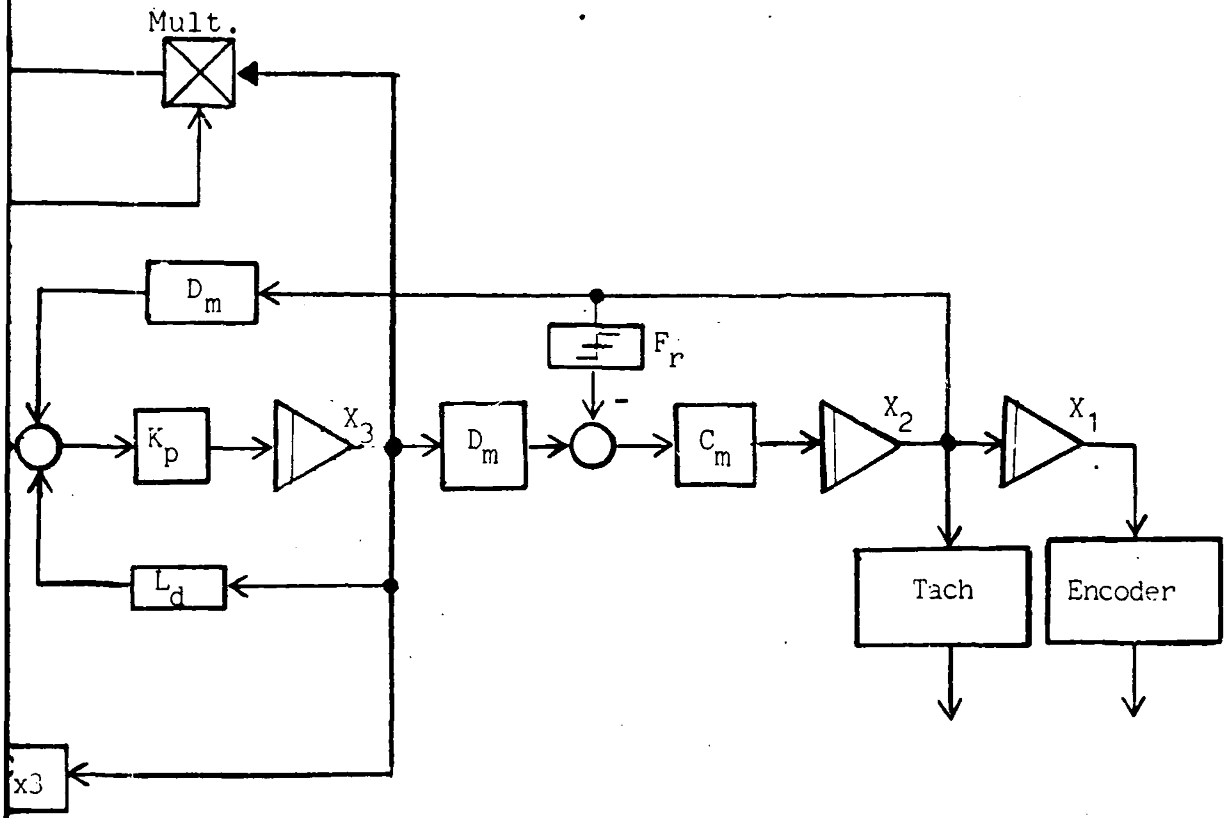
Figure 2.4-1 provides a functional diagram of the hydraulic system. Table 2.4-1 defines the hydraulic system parameters. A Fortran simulation of the hydraulic system showed the system to be lightly damped even with all the control gains equal to zero. The response could be improved by providing pressure feedback signals into the input to the servo valve controller amplifier. However at NRL for reasons discussed in the Results Section, differential pressure feedback was implemented through the digital processor and was less effective than it may have been using analog feedback.

Figure 2.4-2 illustrates the control functions presently implemented into the system. Although the capability exists in the system for implementing certain control functions in analog circuitry, the present system is implemented as illustrated with the digital output control signal passed through a D/A converter and applied directly to the input of the hydraulic valve.



$$C_{sr} = K_s \sqrt{P_s - P_1}$$

FIGURE 2.4-1: Hydr



Hydraulic System Model

TABLE 2.4-1: Hydraulic System Parameters

Parameter	Value
C_{sp}	$(50*2\pi)^2$
C_{sv}	$(2*.4)/(50*2\pi)$
$C_{sr} = K_s\sqrt{Ps-P_s-P_1}$	-
K_s	274 in^3/sec/in.
P_s	500 psi
K_p = B/V	865 lb. in.
B	2.5×10^5 lbs/in^2
V	289 in^3
L_d	.0265 in^3/sec/psi
D_m	3.32 in^3/in.
$C_m = 1/m_i$	-
M_1	.309 lb. sec^2/in.
M_0	.246 lb sec^2/in.
*C_{x3}	0.0

Other Parameters of Interest:

1) 10 V. input = 244.8 in/sec. = 12.24 R/s (max)

2) Amax = 2682 in/sec^2

$\simeq$ 134 R/s = max

*Pressure feedback analog gain function.

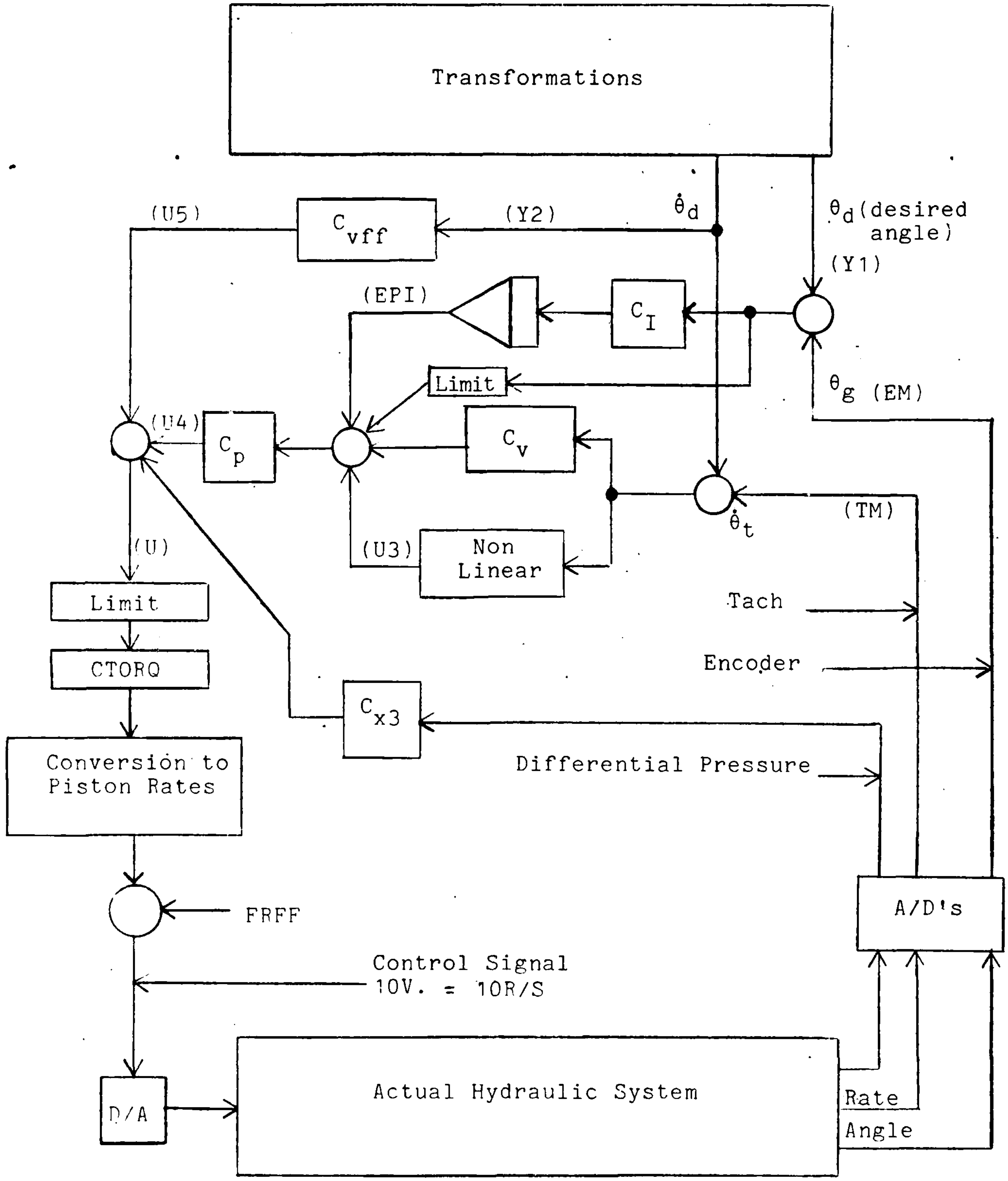


FIGURE 2.4-2: Digital Control Functions

Differential pressure, rate and angle are converted to digital form and fed into the computer for use in defining the required output control signal.

As described in previous sections, the control inputs are passed through appropriate transformations to derive the desired angle and angular rate for each of the two gimbals. The desired angle is compared with the measured angle and the error, amplified by control gain C_p, fed back into the control system in the direction to null out the error. The error is also applied through C_I to an integrator to provide intregal control to drive the error to zero even in the face of large disturbance torques such as friction and/or unbalance.

The desired angular velocity is compared to velocity as measured by the tachometer, multiplied by the damping gain, C_v, and summed with the other control signals. Velocity error is also passed through a non linear gain which when non-zero increases damping as velocity is increased. However, at present non linear gain is set to zero.

The desired angular rate is also fed along a feed forward path through the gain C_{vff} and summed with the other control signals. As discussed previously, a constant input into a hydraulic system of the type utilized here results in constant velocity. Therefore the desired velocity is multiplied by the appropriate gain to cause the system, after the initial transient, to move at the desired velocity with other components of control equal to zero.

Another component of the control is the differential

pressure feedback through gain C_{x3}.

The overall control signal is limited to prevent overdrive of the system. It is multiplied by appropriate conversion gains such that the digital signal fed to the D/A actually represents the desired velocity defined by the (hydraulic flow rate) of the hydraulic pistons. Note also that a signal can be inserted to try to cancel out the some effects of friction although at present this signal is set to zero.

The digital portions of both control loops operate at 512 samples per second. Measurement of pressure, angular rate and angle aremade after completion of the transformation computations and just prior to computing the control signal. This minimizes transport lag to less than 400 micro seconds between the time that the measurements are made and the outputting of the control.

2.4.2 ANALOG FUNCTIONS

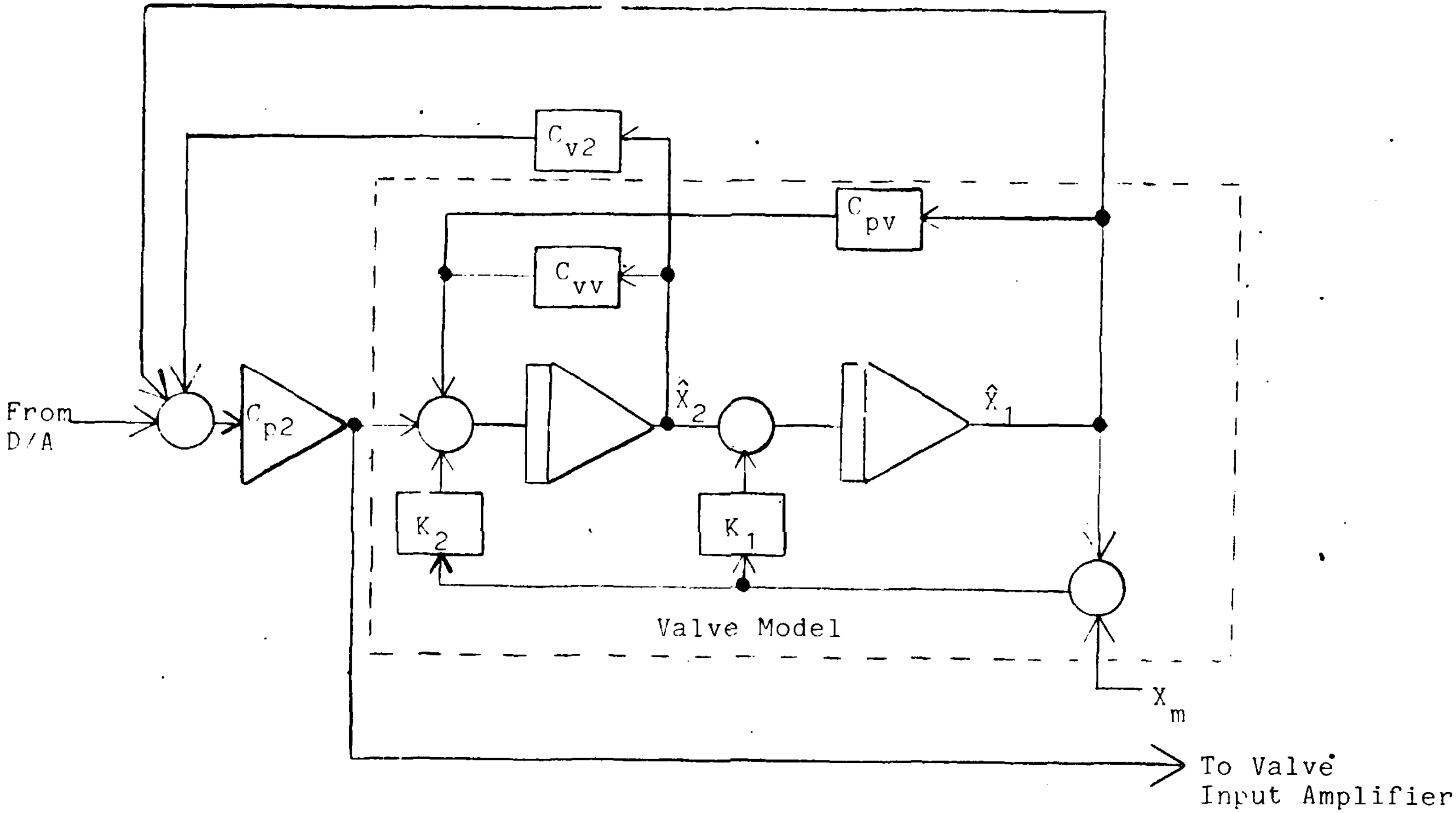
The original intent was to investigate the implementation of certain functions in analog. Although use of a digital computer greatly facilitates implementation of non-linear and complex functions, none the less sampling generally degrades stability margin within control systems. Implementing certain functions which require high frequency response in analog bypasses the effect of transport delays and time discrete outputs.

The system hydraulic pressure was 500 psi, considerably below rated pressure for the valves used within the system. This resulted in a degradation in response of the hydraulic system. To improve valve response, the control signal going into the valve was provided with signal shaping providing phase lead. The

circuit utilized for this is illustrated on Figure 2.4-3. In this circuit the dynamic response of the valve was modeled, using analog circuitry, providing estimates of spool position and spool velocity. Spool position was compared with measured spool position and corrections made on the model. Since velocity within the model is accessible additional valve damping could be provided permitting an increase in displacement gain. This provided an apparent increase in valve dynamic bandwidth. Note that the output that feeds into the valve model is also fed into the input of the actual valve amplifier. Test on the model indicated that some improvement in valve dynamics was possible using this approach. However, non-linearities within the valve created uncertainties and at present this circuitry is bypassed awaiting further tests to either prove or disprove its advantages.

Within the interface units supplied by Navtrol is the capability to sum various signals with the signals from the D/A converter before applying the sum to the hydraulic system input. As indicated previously, it was planned to investigate analog feedback of both pressure and tachometers signals to see what advantages would be gained. A signal porportional to differential pressure was derived within the interface unit and could readily be summed in with the D/A output. However satisfactory tests were never completed on this aspect and at present this feedback gain is set to zero.

It was planned to feed the tachometer signal through a multiplying D/A converter before summing it with the other inputs. The digital input into the multiplying D/A was to modify



$\hat{X}_1$ Valve Spool Estimated Position

$\hat{X}_2$ Valve Spool Estimated Velocity

X_m Measured Valve Spool Position

FIGURE 2.4-3: Valve Signal Shaping Functional Diagram

the analog signal from the tachometer mounted on the gimbals such that the signal more closely represented the velocity of the hydraulic pistons. This portion of the system was never tested and is presently not being used.

2.5 CONTROL INPUT FUNCTIONS

2.5.1 GENERAL DISCUSSION

The All Digital Controller System for NRL permits the selection of 9 different functions for the antenna to perform. These functions are as follows:

Ø=IDLE
1=INITIALIZATION
2=TRACK
3=TRACK TARGET
4=SINE WAVE INTO GIMBAL
5=SINE WAVE INTO TARGET
6=SCAN GIMBAL
7=SCAN TARGET
8=STOW
9-RESET TARGET DIRECTION ANGLES

Except for the first two functions, which accomplish very little, the even functions are the gimbal functions, and the odd functions are the target functions. The gimbal functions control the gimbals directly while the target functions direct the beam, commanding the appropriate gimbal angles to point the beam in the desired direction. The beam is controlled in inertial reference coordinates with appropriate transformations included to provide appropriate controls to each of the antenna gimbals. Gimbal functions can be selected for either axis or both axes. However, since target parameters cannot apply to specific axes as such, when target functions are selected it is assumed that these go into both axes, except when one axis is in idle. In this case

the "Idle" gimbal will not move while the other axis will move through the gimbal angle commanded. This permits testing of various functions, at least to some extent, even though one axis is temporarily down.

The ability to select different functions for the two axes is especially convenient during test modes in the gimbal axes. One axes at a time can be commanded to perform sine waves, scan routines or follow ramp inputs while the other axis is idle.

Control is presently accomplished through use of the Navtrol provided CRT keyboard and Front Panel Computer. However, control from another computer can be accommodated.

Paragraphs which follow describes each of the functions which can be selected.

2.5.1.2 FUNCTION Ø: IDLE

This is a do nothing function in which the ADC, although in the operate mode, sends out no commands, reads back no data from the encoder, tachometers or pressure transducers and exercises only a portion of the program. One axis can be commanded to the Idle function while the other axis performs any of the other nine functions.

2.5.1.3 FUNCTION 1: INITIALIZATION

The initialization function for the NRL system does very little, functioning essentially the same as the IDLE function. It has been set aside for use when initializating certain system parameters should that be required. Parameters such as limit switch position could be determined, if required. (In certain systems locating the index position of an incremental encoder has been an important initialization function, but not here.)

2.5.1.4 FUNCTION 2: TRACK GIMBAL

In this function the antenna gimbal angles are commanded to continuously point the antenna using one of eight sets of commanded gimbal angles. The particular set of gimbal angles selected will change if the commanded velocity is other than zero and the antenna will follow. Integration is performed only on the set of gimbal angles selected for use. If another function is commanded or another set of gimbal angles selected, gimbal directions are reset to the original direction commanded. Gimbal angles and velocities must be selected prior to exercising this option.

2.5.1.5 FUNCTION 3: TRACK TARGET

Any of 8 targets can be tracked using this function. Targets can be moving or stationary depending on the velocity inserted when setting the target parameters. This capability is illustrated on Figure 2.5-1. The eight targets are all defined in the inertial reference coordinate system. Theta is the angle above the horizon and psi is the azimuth angle measured CW from north. (East is 90 degree.) At present the initialized data assumes a ship headed north with decks horizontal so that pitch and azimuth angles also apply with respect to the ship. Relative angles can readily be changed by entering appropriate ship's attitude angles. Directions entered in the target mode define beam direction, not gimbal angles, taking into account all the coordinate transformations and the complex "half" angle relationship for the mirror. All 8 targets are integrated from the time they are entered, or from the time the ADC is placed in

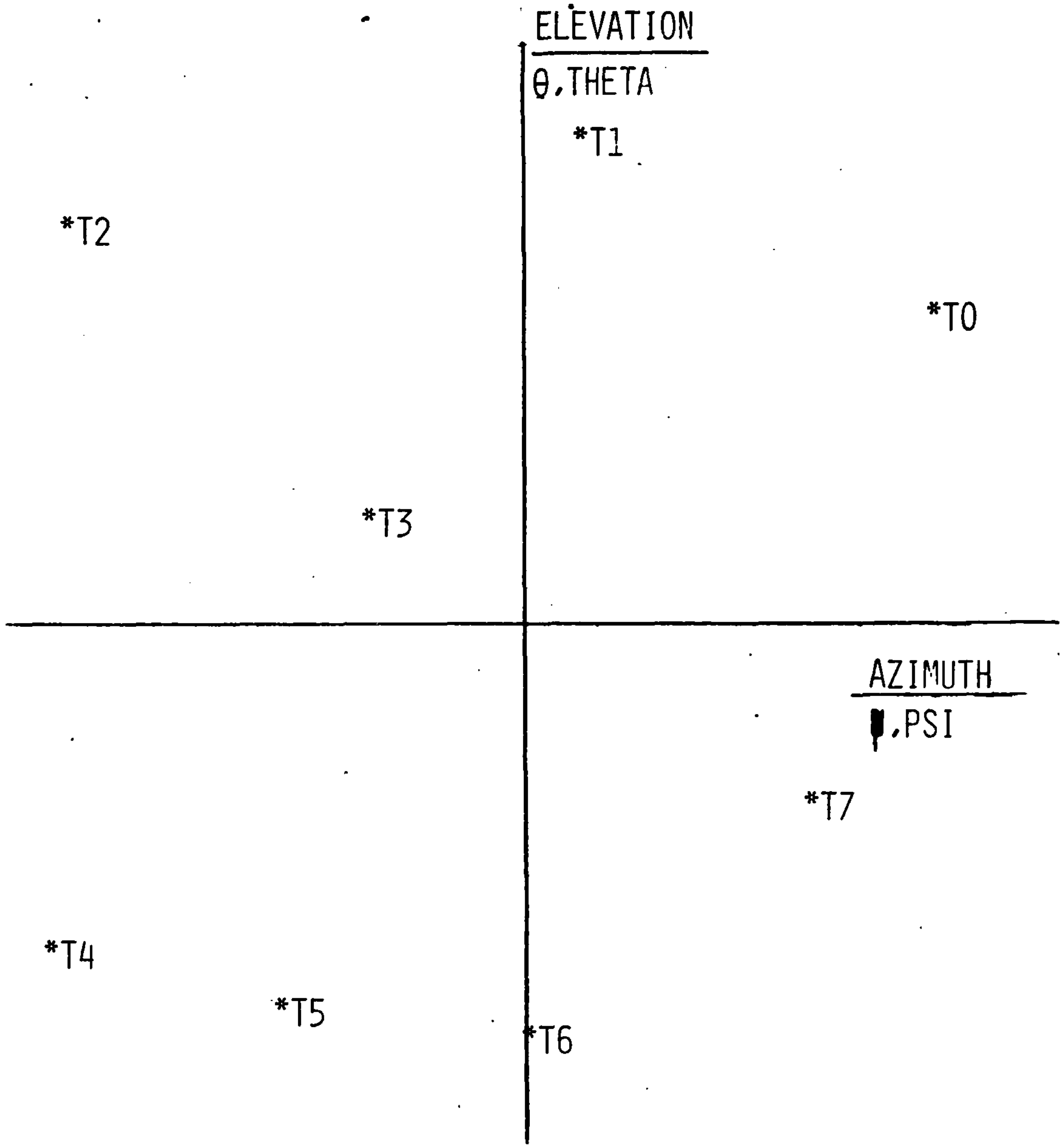


FIGURE 2.5-1

EIGHT MOVING TARGETS CAN BE ACCOMODATED
BY THE ALL DIGITAL CONTROLLER SYSTEM

the "Operate" mode, whichever occurs later. Steps from target to target are readily accomplished by the operator. Targets can be reset at any time to their original direction, either individually or all together.

2.5.1.6 FUNCTION 4: SINE WAVE INTO GIMBAL

This function commands sine waves into the two gimbal angles. The frequency for the two sine waves must be the same but phase relationship and amplitude can be different so that the antenna can be made to scan in a circular pattern, an oval pattern or along a straight line. Note that the gimbal angles are controlled directly, not the beam direction or even the "normal" to the antenna. The sinewaves can be centered about any of the 8 sets of moving gimbal angles defined in Function 2.

2.5.1.7 FUNCTION 5: SINE WAVE INTO TARGET

By use of this function the beam can be caused to scan in a circular or oval pattern, centered about any of 8 targets which are assumed to be continually moving. The function commands beam direction, not gimbal angles, and takes into account the "half angle" relationship of a mirror directing source radiation toward a target. By commanding equal amplitudes of the two sinewaves but a 90 degree phase relationship, the beam can be commanded to define a circle about a moving target. Such a pattern, illustrated on Figure 2.5-2, is useful for target acquisition or reacquisition. Note that if the amplitudes are different an oval pattern results which is useful when the uncertainty is not the same in both directions.

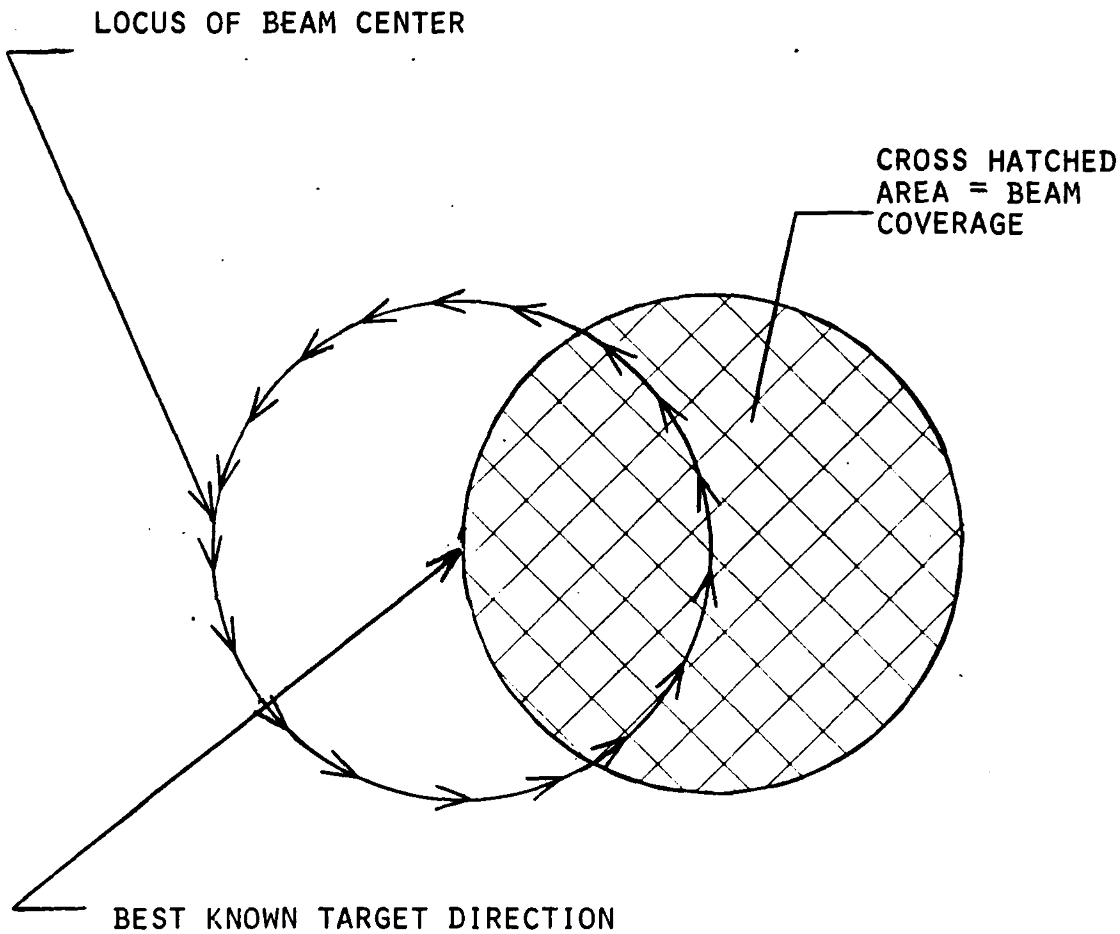


FIGURE 2.5-2: CONICAL ACQUISITION SCAN

2.5.1.8 FUNCTION 6: SCAN GIMBAL

In this function the antenna is commanded to move at constant velocity first in one axis and then in the other so as to enclose a box. To minimize time around the box the scan in one axis actually commences before the scan in the other axis is complete causing the box to have rounded corners. Eight sets of scan widths (or heights) and scan velocities can be defined, with any of the eight sets of gimbal angles at the center of the box. Scan parameters and the center angle are independently selectable.

The commanded pattern moves from one velocity and direction to another at essentially constant acceleration. This acceleration is selected to be within the capability of the antenna. It is the same for both axes. It cannot be adjusted through use of the parameter setting options but can be changed using the Data Memory monitor program.

2.5.1.9 FUNCTION 7: SCAN TARGET

In this function the antenna beam can be made to scan about any of 8 targets. The scan pattern is a box or a rectangle with rounded corners as just described for Function 6. The difference between this function and Function 6 is that the beam is controlled here rather than the gimbal angles. The parameters for this function which must be preset are scan width, scan height and scan velocities. By selecting the Theta scan limit to be very small the antenna can be made to perform a conventional horizontal scan. By selecting the Psi scan limit to be small the antenna can be forced to perform a vertical scan. Both Function

6 and 7 use the same scan routine. A single acceleration parameter applies to both axes and to both functions. It can be changed through use of Data Memory monitor program.

2.5.1.10 FUNCTION 8: STOW

This function is used to point the antenna in a predetermined direction which cannot be altered through use of the parameter setting options. At present the STOW position is 0 Deg. for both gimbal angles. STOW position can be altered by changing the appropriate places in Data Memory. A special function key for STOW is provided to facilitate this function. However, both "STOW" and "Return" must be pressed in succession to stow the antenna.

2.5.1.11 FUNCTION 9: RESET TARGET DIRECTION ANGLES

By selecting Function 9 all of the target direction angles are reset to their originally inserted values negating previous integration. This allows repetition of certain preset patterns for testing.

SECTION 3
SYSTEM HARDWARE DESCRIPTION

3.1 OVERALL SYSTEM

Figure 3.1-1 illustrates the components of the overall antenna control system supplied by Navtrol. The items above the dashed line represents components of the system supplied by NRL. Components below the line, with the exception of cables tied in with NRL supplied components, were supplied by Navtrol. The All Digital Controller main unit, CRT and diskette unit, keyboard and graphics printer are all standard components supplied by Navtrol and illustrated in Figure 1-3 in the Introduction. On Figure 3.1-1 the sizes of the various units are indicated in terms of width, height and depth. Two Interface, Units identical to each other, and contained in aluminum boxes measuring 6.5" x 2" x 4.5", were custom built for this application and are also shown. Communication between the All Digital Controller and these units is over a 2 Mbits/second serial interface consisting of four differential lines. Plus 8, plus 16 and minus 16 volts of unregulated DC power is supplied from the All Digital Controller to each of the two Interface Units.

3.2 ALL DIGITAL CONTROLLER

3.2.1 ADC DESCRIPTION

A brief description of the All Digital Controller is contained in the Introduction to this report. Provided to NRL in a separate document is a complete description of the All Digital Controller. Figure 1-2 in the Introduction illustrates the portion of the All Digital Controller which provides the

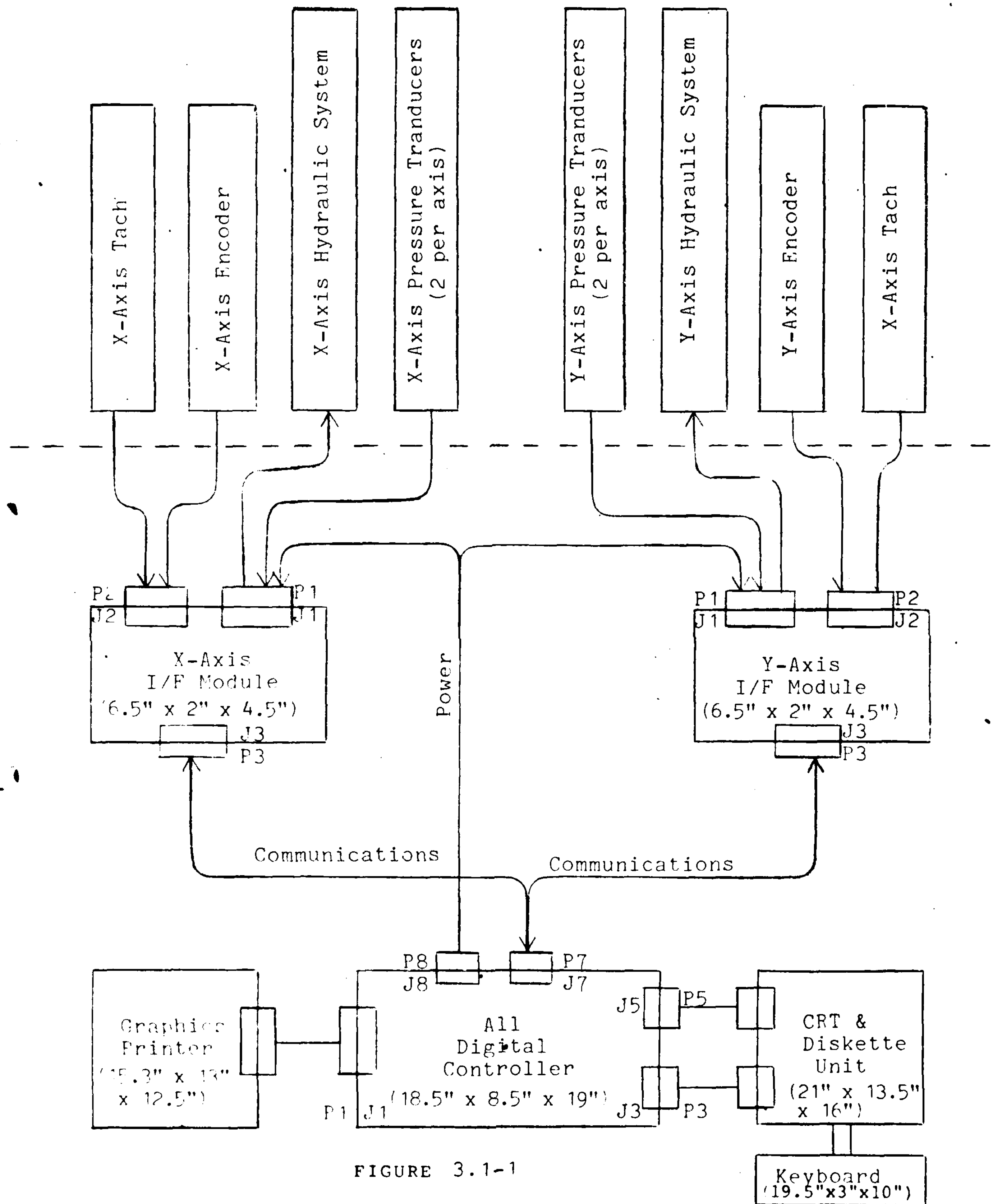


FIGURE 3.1-1

Antenna Control System Interconnection Diagram

computation involved in the transformations and control of the antenna. This computer can in turn be controlled or supervised from the Front Panel Computer, described below, or from another computer through appropriate interfaces.

The All Digital Controller is a fast, programmable machine dedicated to servo control of multi axis or highly complex systems. Figure 3.2-1 is a photograph of the Digital Controller with the cover removed. Visible are two card cages. The rear one is for the "Front Panel Computer" and the front one is for the "All Digital Controller Processor Unit". In addition to the two card cages, the case contains a Front Panel Light and Switch I/F Board and power supplies. The ADC Processor Unit and Front Panel Computer communicate through either serial or parallel interfaces and, if desired, the ADC Processor Unit can be remotely located away from the rest of the system. The rear located Front Panel Computer, referred to as the FP controller or FP computer, allows the operator to monitor and/or change every word in Data or Program Memory of the ADC Processor Unit. Only three boards in the Front Panel Computer, the Z80 CPU, PROM Memory and FP Interface, are required to perform the functions just described. The other boards, 64K RAM Memory, Disk Interface and Video Control Boards, provide additional capability for software development and control system monitoring.

As indicated, the Front Panel Computer includes a Z80 based CPU and is primarily intended as a smart interface between the digital controller and the human operator. It also acts when required as a component of the Servo Develoment System in

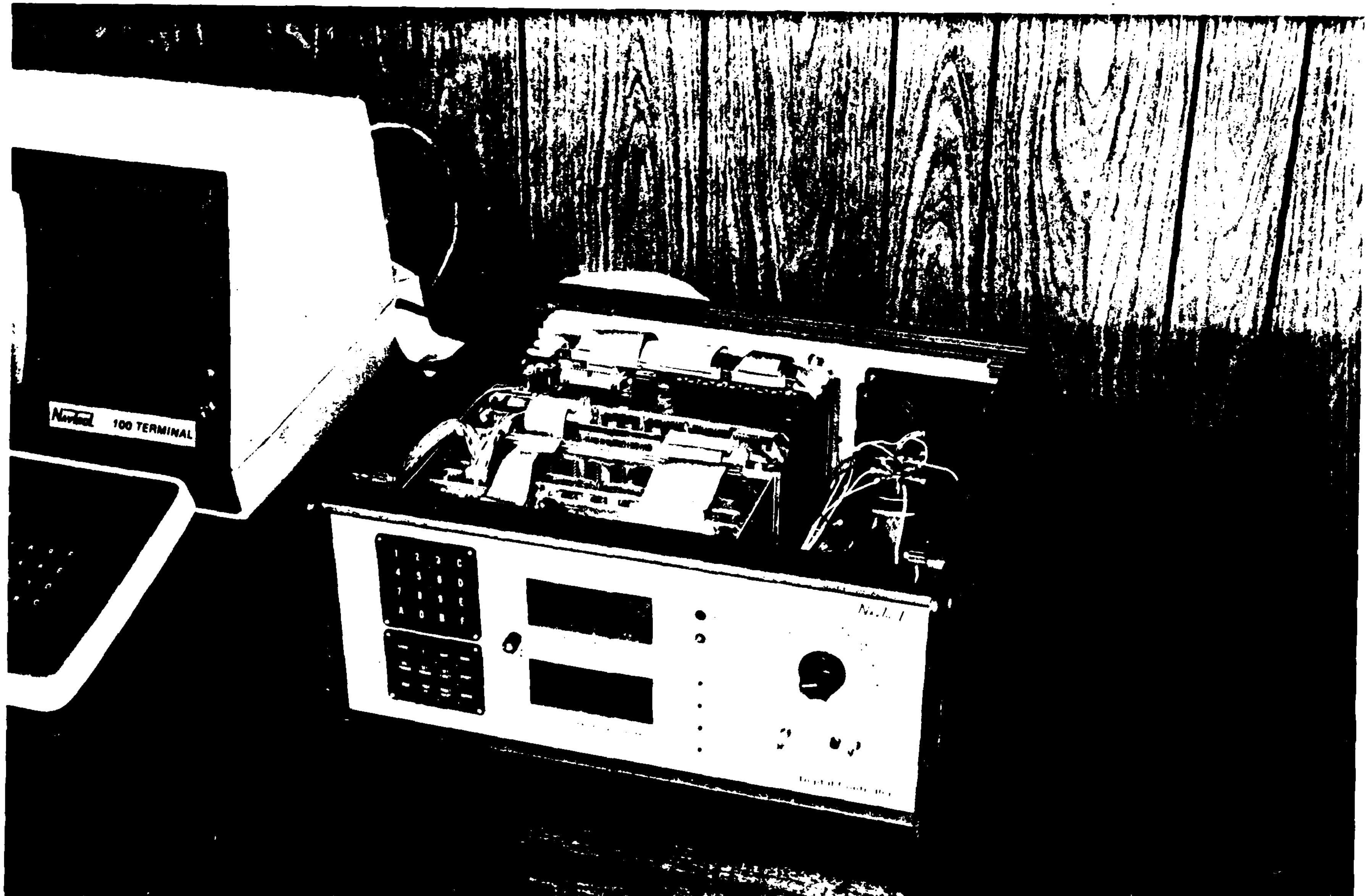


FIGURE 3.2-1: Photograph of the Main Unit of the Digital Controller

developing software and/or monitor performance of the All Digital Controller Processor, requiring the additional memory and interface boards shown in the photograph, to accomplish the task.

Table 3.2-1 describes further the feature of Navtrol's ADC system. The heart of the system is a digital processor designed specifically for closed loop control of multi-axis or highly complex servo systems. High speed, special architecture and special commands set it far above micro processors or mini computers for control applications. The processor features are summarized in Table 3.2-2.

Although control and monitoring of the system is normally possible from the front panel of the All Digital Controller Unit, it is much more flexible and extensive when using the full Software Development System shown in Figure 1-3 in the Introduction. Full menu prompting is provided on the CRT for commanding 9 separate functions, included within the NRL System. The setting of parameters for sine wave or box scans as well as the location of 8 targets, about which the various functions can be performed, can be inputed through the CRT, also with menu prompting as required. Time responses for various types of inputs can be plotted on the CRT and reproduced on the printer .

3.2.2 ADC OPTIONS

On the ADC Processor Unit PC boards there are several hardware options which must be correctly set in order for the system to function correctly. Table 3.2-3 defines how each option should be selected for the NRL control system. The "Description of the All Digital Controller", provided to NRL as a separate document, describes these hardware options further but

TABLE 3.2-1

Features of the All Digital Controller

1. A processor designed specifically for control applications which can handle eight complex control loops each having a bandwidth of 10 Hz.

2. A system approach whereby all communications along lines which cross gimbals is accomplished digitally. Compact modules such as power amplifier and encoder interfaces can be located adjacent to the associated motor and encoder. As many as 128 such units could be addressed.

3. Inter-unit communication can be parallel or serial. Serial communication utilizes 4 differential transmission channels including clock.

4. Hardware and software designed together for maximum compatability, providing outstanding performance while utilizing minimum hardware.

5. A programmable Front Panel, utilizing a microprocessor, provides supervisory control over the main processor, telling it what function to perform and what data is to be presented.

6. Complete monitoring and programming capability from the Front Panel including access to every word in both Data and Program Memories.

7. A Servo Development System including a graphics CRT, a graphics printer, dual disk drives, graphics software and Software Development System software.

TABLE 3.2-2

PROCESSOR FEATURES

1. 16 bit parallel processing.

2. Extremely fast computation times
   a) Add from memory, 298 nanoseconds.
   b) 16 bit multiply from memory, 2.7 microseconds.
   c) Memory and I/O access time, 298 nanoseconds.

3. Speed achieved through simplicity of architecture---not through use of ECL, Schottky or other very high speed, high power type integrated circuits.

4. Maximum use made of "Low Power Schottky" TTL circuits with low power consumption and proven reliability.

5. Simplicity of approach further enhances reliabililty and reduces size and cost.

6. Hardware and microcode design facilitates magnitude comparisons and limit functions used so frequently in control system applications. The magnitude of each piece of data can be quickly compared with expected values and thrown out and/or alarms issued.

7. A micro-program especially designed for control system usage.

8. By use of memory address indexing, the program required for multiple control loops can be contained in the number of program control words usually required for only one.

9. Use of RAM for program storage as well as data storage facilitates changes to accomodate various requirements.

10. Sine look up table provides for fast coordinate transformations.

11. Addressing data memory from the accumulator provides the capabililty for creating and using additional "look up" tables.

TABLE 3.2-3

Selection of ADC Hardware Options for NRL
(Refer to Tables 2.1-11 and 2.1-12 in the
"Description of the All Digital Controller" document.)

Option No.	Selection
1.	Select Address Bits Ø and 1 to be indexed.
2.	Select Two as the number of Address Bits to define Indexed or Non-Indexed Instructions.
3.	Select either 2K of Data Memory 1 or 1K each of Data Memory 1 and Data Memory 2.
4.	Always select Parallel Communication to FP Computer (or PDP-11 Computer) except when using the FP Computer in the Serial Communication Mode for Loading Program Memory.
5.	Select 512 Sync Pulses per Second.
6.	Select 2MHz for I/O Clock Frequency.
7.	Select On Board Clock for SIO Received Data.
8.	Select Clear mode for Power-On.

does not define the selection required for the NRL system. These options were all properly set prior to delivery of the system.

3.3 NRL SYSTEM INTERFACE UNITS

3.3.1 GENERAL DESCRIPTION

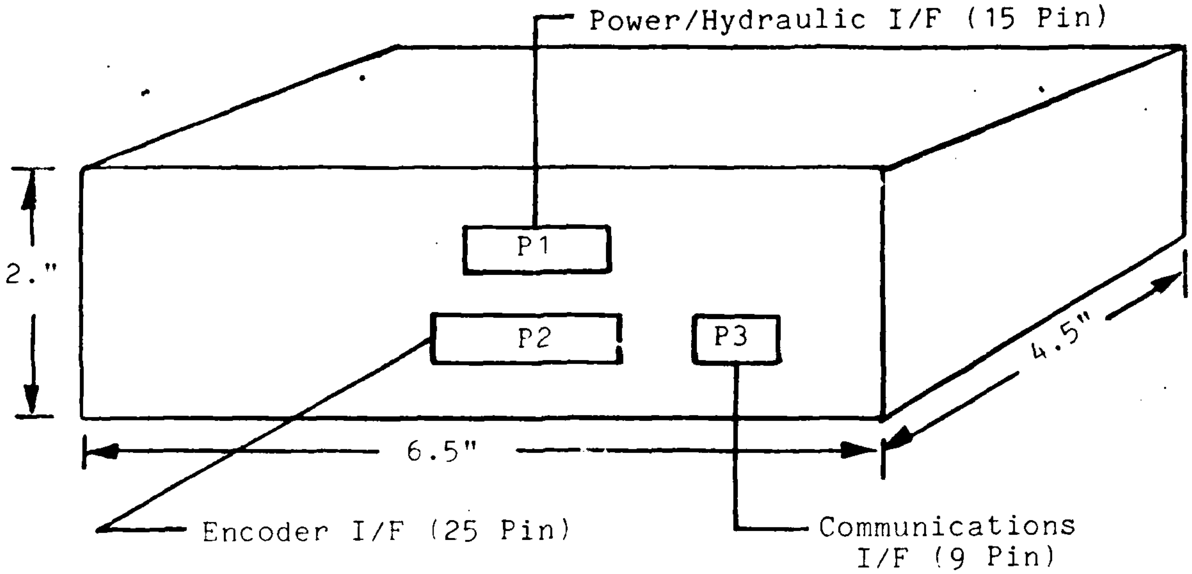
Figure 3.3-1 provides a sketch showing the dimensions of each of the two Interface Units and includes a list of the contents. Each unit contains two circuit boards. On the upper board interconnections were made using the wire wrapping technique of the Gardner Denver Corporation. The lower board is a printed circuit board. Contents of both the upper and lower boards are listed on Figure 3.3-1.

Figure 3.3-2 is a functional diagram of the circuitry contained in the NRL interface unit. Sections which follow describes these functions.

3.3.2 COMMUNICATION INTERFACE CIRCUITRY

The communication circuitry allows serial communication with the ADC processor unit over 4 differential signal lines operating at 2 MHz. The primary component of this circuitry is a standard serial communication module manufactured by Navtrol and described in the "Description of the All Digital Controller" provided as a separate document. Additonal logic provides decoding so that the single module can be used to communicate with 5 different functions. These 5 functions are listed on Table 3.3-2. The notation "Sent to the I/F Unit" indicates the signal is sent from the ADC processor to the interface module using the Send IO (SIOS) instruction. The "Received from I/F Unit" notation indicates that the data flow is from the interface unit to the

FIGURE 3.3-1: NRL Interface Units



Each Unit contains 2 Circuit Boards:

A. Upper board (W.W. Board)

1. 5 V. Regulator
2. ± 12 V. Regulator
3. Hydraulic I/F Circuitry
   (1) Valve Phase Lead Circuit
   (2) Pressure Sensor Exitation
   (3) Differential Pressure Measurement
4. Connectors:
   (1) Power/Hydraulic I/F (15 Pin, "D")
   (2) Connector to Lower Board (20 Pin)

B. Lower Board (P.C. Board)

1. Communication I/F Module and Added Logic
2. Absolute Encoder I/F (16 bit)
3. Control D/A (to Hydraulic Amplifier)
4. Tach Conversion MDAC
5. Multi-input A/D Converter
6. Connectors
   (1) Communication I/F (9 Pin "D")
   (2) Encoder - Tach I/F (25 Pin)
   (3) Connector to Upper Board (20 Pin)

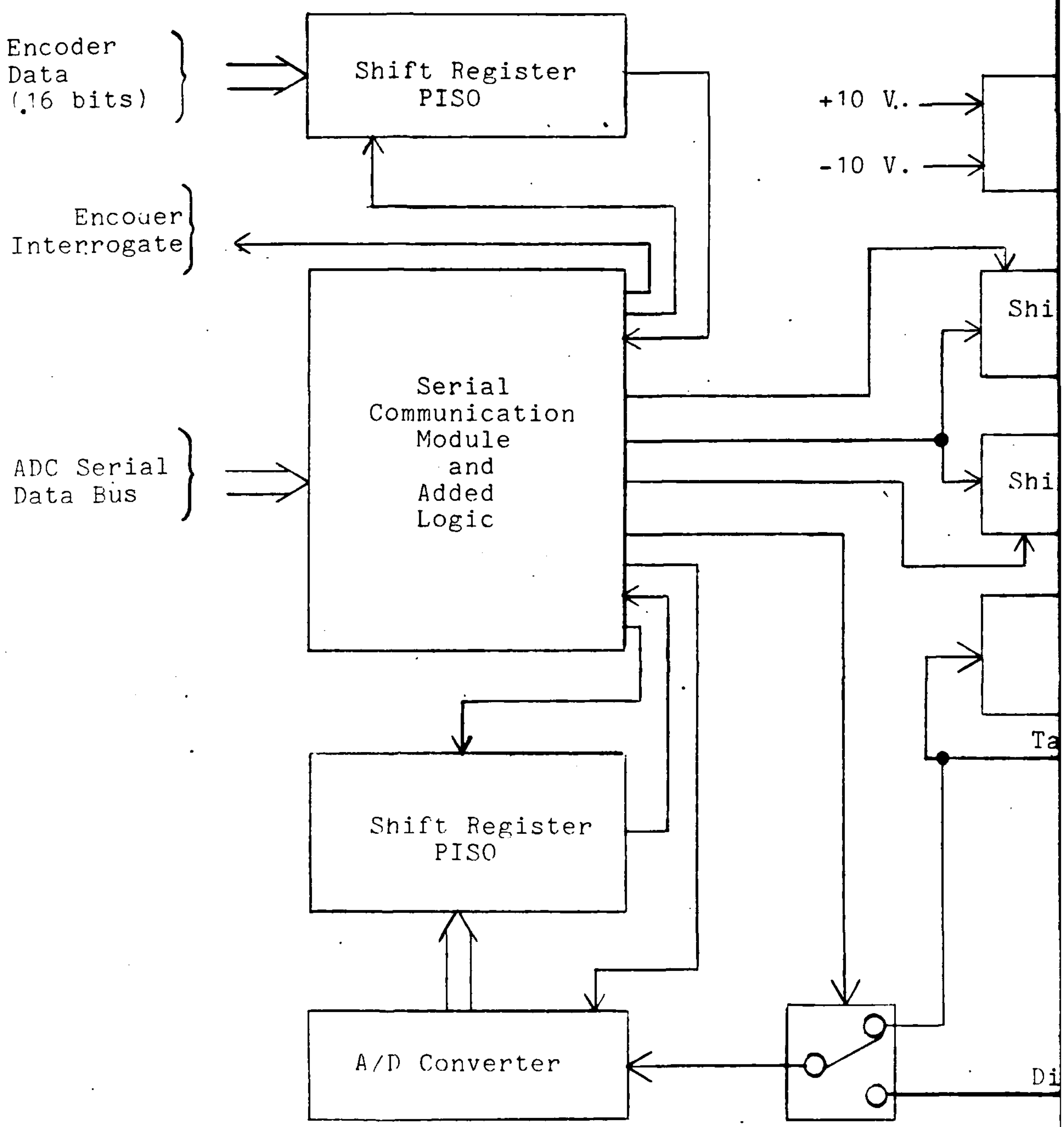
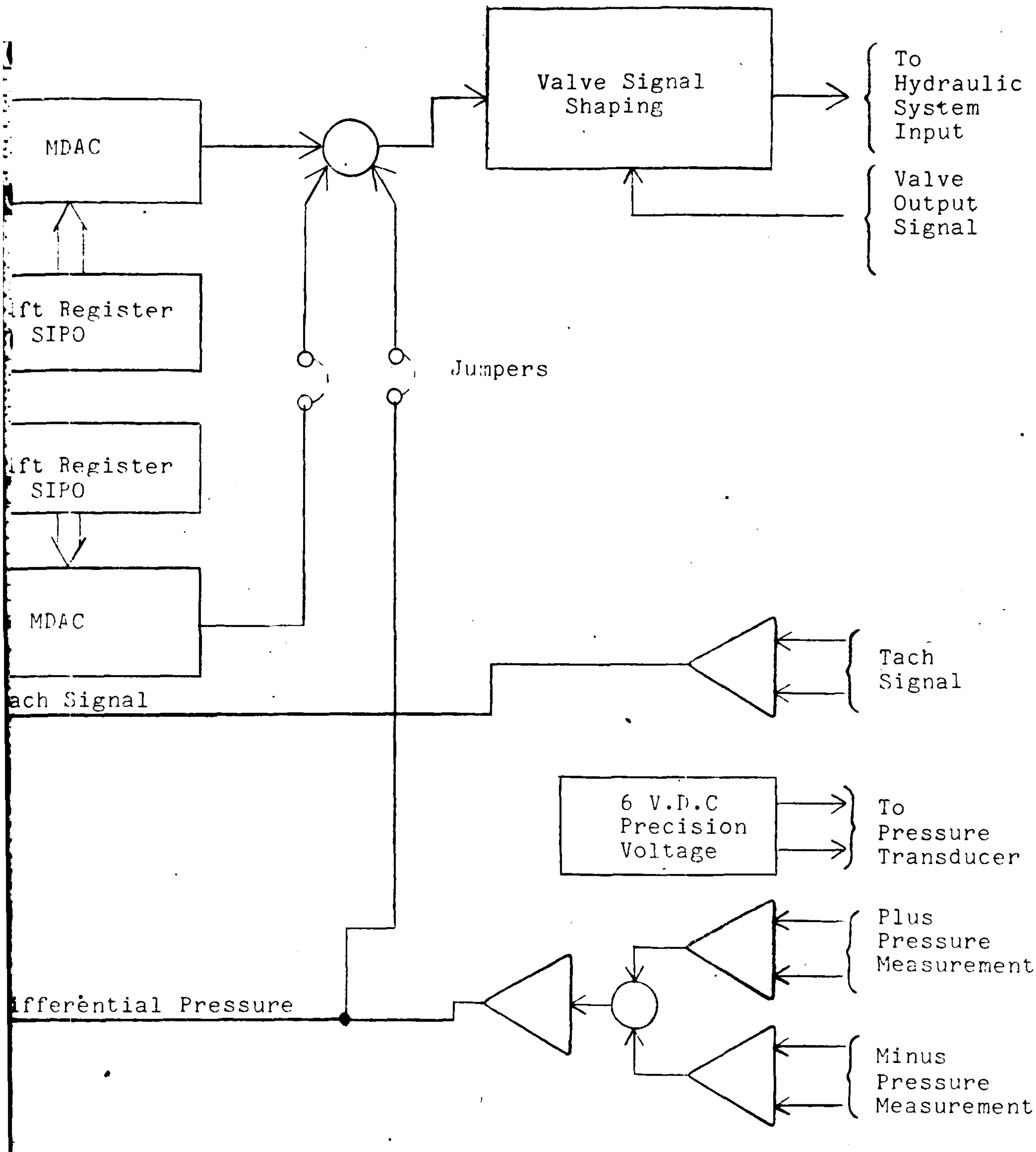


FIGURE 3.3-2: NRL Interface



e Unit Functional Diagram

TABLE 3.3-2:

I/F Function I/O Requirements

1. I/F Function and Address

I/F Function	X Axis Address	I/F* (HEX)
1) Tachometer Conversion (Sent to I/F Unit)	64	
2) Pressure Measurement (Received from from I/F Unit)	F4	
3) Tachometer Measurement (Received from I/F Unit)	F4	
4) Encoder Measurement (Received from I/F Unit)	E4	
5) Hydraulic System Control Input (Send to I/F Unit)	74	

2. Data Formats

1) A/D Output I/O Data Format

DR (1 bit)	Not Used (5 bits)	A/D Data (10 bits)

MSB — LSB

2. Hydraulic System Control Input Format

Sign (1 bit)	Not Used 5 bits)	Command Magnitude (10 bits)

MSB — LSB

*Y-axis address is the X-axis address plus one, or 65, F5, F5, E5 and 75 for the five functions respectively.

ADC and is accomplished by means of a Receive IO (RIOS) Instruction.

The order of the above commands must be adhered to because of the nature of the decoding circuitry. The "Tach Conversion" capability is not presently used but this signal must be sent since it not only performs the tach conversion function of loading a D/A but also results in an interrogation signal being sent to the encoder (see following sections) and the A/D converter commencing to convert the differential pressure measurement. A flip flop is also set at this time to select the differential pressure signal over the tachometer signal for A/D conversion. Note that both these functions have the same address and are told apart buy the order they are received. The A/D converter requires 25 micro seconds to complete its conversion and sufficient time must be allowed within the software program to complete this conversion before reading back differential pressure.

When the differential pressure measurement is commanded to be sent back to the ADC, the A/D input select flip flop is reset to switch the A/D input to measure the tachometer signal. This occurs at the time that the differential pressure measurement is loaded from the A/D into the shift registers.

There are two sets of parallel in serial out (PISO) shift registers on the PC board. The first set accepts the signals from the A/D converter while the other accepts the data from the 16 bit absolute encoder. A flip flop selects the set of shift registers whose data will be communicated back to the ADC. This

flip flop is set when the differential pressure measurement is commanded to be sent back to the ADC to select the shift registers associated with the A/D converter. It is reset at the time that the encoder data is loaded into shift registers to prepare for sending this data back to the ADC.

After the interrogate signal is sent to the encoder triggered by the tach conversion command, 100 micro seconds is required to insure that the encoder data is ready. Sufficient time must be left within the ADC software program such that the encoder measurement is not loaded into the shift register until this amount of time has elasped.

The last of the 5 interface functions is the sending out from the All Digital Controller to the I/F Unit the hydraulic system control input. When this command is loaded into its register, a retriggable one shot is retriggered to indicate that commands are being received within the proper time intervals. If a hydraulic command is not received within approximately 1 milli-second the D/A output will be set to zero. This is a fail safe feature to protect the antenna from damage should the Processor Unit fail. This feature can be combined with a diagnostic routine within the Processor Unit to provide almost 100 per cent protection in case of even partial malfunction of the ADC processor unit. Development of such a routine was not included within the NRL system.

Each interface unit and each function within the unit is assigned an ID address code to which it responds. At least a portion of the address code is wired into the 25 pin encoder IF connector. This enables the two interface units, for the X axis

and the Y axis, to be interchanageable with their address determined by the cable to which they are connected. The assigned I/O address of each interface unit and the functions within the unit were given on Table 3.2-2, previously presented. Also given on this table is the format of the data words used in communicating with the ADC Processor Unit for the A/D Outputs and Hydraulic System Control Input. All 16 bits of the Encoder data word are used for data. The "Tach Conversion" data word is like the Hydraulic System Control Input except there is no sign required since the digital word is always positive. The data words of all five functions are 16 bit with the MSB on the left, although in most cases all 16 bits are not used.

3.3.3 TACH CONVERSION MULTIPLIER FUNCTION

As described in Section 2.4.2 the "Tach Conversion" multiplier function is a multiplying D/A converter which multiplies the analog tachometer signal times the digital signal applied to the MDAC. The resultant signal, roughly proportional to piston velocity, can be summed with other control signals and fed through the valve signal shaping circuit to provide additional system damping. The digital multiplying signal must be always positive but the analog signal can go plus or minus.

The Tach Conversion function is presently not being used. However, loading the MDAC also triggers several other events so that calling this IO function must remain within the software program. Other events triggered, as discussed in Section 3.2, are the triggering of the encoder interrogate signal, the setting of the A/D input flip flop to select the pressure measurement

and the triggering the start of the A/D conversion function.

3.3.4 DIFFERENTIAL PRESSURE MEASUREMENT

As indicated in Section 2.4.2, pressure measurements are provided by 2 pressure transducers per axis mounted at the base of the differential hydraulic pistons. Excitation for these two transducers is provided by a precision 6 volt supply within the Interface Unit. Signals from the transducers is amplified by high gain, low drift amplifiers and summed in such a way as to provide a signal representing differential pressure. The signal can be amplified and summed with the other control signals to provide pressure feedback directly, by-passing the processor. The differential pressure is also applied to a A/D converter and transferred back to the processor unit for monitoring and/or control usage.

3.3.5 TACHOMETER SIGNAL

For measuring angular velocity, tachometers are provided on the gimbals of the DMAR amtenna. The signal from the tachometer is amplified and fed both to the MDAC for the "tach conversion" function and to the A/D converter through the A/D input switch. Gain adjustment for the tachometer signal is provided.

3.3.6 A/D CONVERTER CIRCUITRY

A ten bit A/D converter, used to convert the analog signals representing differential hydraulic system pressure and velocity as measured by the tachometer, is included wthin the NRL Interface Unit. The A/D converter used is an AD571 which requires about 30 micro seconds to perform the conversion. As indicated in the previous section, the A/D conversion of pressure is initiated by the same signal which stores data into the "Tach

Conversion" register. This same signal presets a flip flop which in turn selects the pressure signal for A/D conversion. A minimum of 30 micro seconds is allowed for the A/D conversion of the differential pressure signal to take place.

When a reading of differential pressure is requested from the interface Unit by the ADC, the data from the A/D converter is loaded into as set of shift registers. At the same time, a second flip flop is set which selects the data from this particular set of shift registers for transferral through the communication inteface back to the ADC. The communication module and the additional communication logic provides the shift clock and shift control required to shift data back through the communication link to the ADC. The load shift register signal also clears the A/D data select flip flop so that the A to D input is now connected to the tachometer signal. The one shot which starts the A to D conversion is again triggered, but this time using the "CLR" input. (On the type of one shot used, the "CLR" input holds the one shot in clear while it is low but fires the one shot when it goes high.) The IO address for reading the tachometer signal is exactly the same as the address for reading the pressure signal. When a "read tachometer signal" is received by the interface unit the A to D converter data is loaded into the set of shift registers and sent back to the ADC just like before. It might be noted that another A/D conversion is started by the signal that loads the PISO with the tachometer signal, but no use is made of this conversion.

3.3.7 ENCODER INTERFACE

Absolute encoders are used on the gimbals to read out the gimbal angles. Sixteen bits of encoder data are loaded directly into a pair of parallel in-serial out (PISO) shift registers with the Interface Unit.

From these shift registers the data is communicated back to the ADC. The data is in 2's compliment format, ready to use within the ADC. At least 100 micro seconds prior to reading in the data an encoder interrogat signal must be issued. This interrogate signal is issued by the same signal that loads the "Tach Conversion" MDAC. A flip flop is set when the encoder data shift registers are loaded. This flip flop selects data from this set of shift registers to pass through the communication module to the All Digital Controller. The interrogate signal originates from the same one shot that starts the A/D conversion but is passed out to the encoder only at the time that the "Tach Conversion" load command is issued. A special open collector drive interfaces the encoder interrogate signal to the encoder.

3.3.8 HYDRAULIC SIGNAL CONTROL INPUT

The serial in parallel out shift register utilized in the Interface Unit, the 74LS673, contain not only a 16 bit shift register but another 16 bit register which stores shift register data at the proper load command. The data in the storage register is fed to a 10 bit Multiplying D/A Converter (MDAC) for conversion to analog. The data in the storage register is sign-magnitude format with the sign bit in the MSB position. The lower 10 bits represent magnitude. The sign bit operates a switch which applies either a + or - 10 volts to the MDAC input. This,

combined with the magnitude provides the appropriate control signal for the hydraulic system. At this point the signal can be summed with analog control signals before feeding through the valve shaping network or directly into the hydraulic control system.

3.3.9 VALVE SIGNAL LEAD SHAPING CIRCUITS

The combined control signal can be fed directly or through a valve signal lead network into the hydraulic valve amplifier. The valve signal lead network is not a conventional lead network. It contains a model of valve dynamic characteristics and uses a signal fed back from the valve to correct an internal estimated valve position. A functional description of this circuit is provided in Section 2.4.2. The purpose of this network is to provide an apparent bandwidth increase for the valve. In the present system because of time constraints this circuitry has not been throughly tested and is bypassed, with the summed signal fed directly into the hydraulic system. In addition, at present the only signal used for control is the digital signal converted to analog by the MDAC described in the previous section.

SECTION 4
SYSTEM SOFTWARE DESCRIPTION

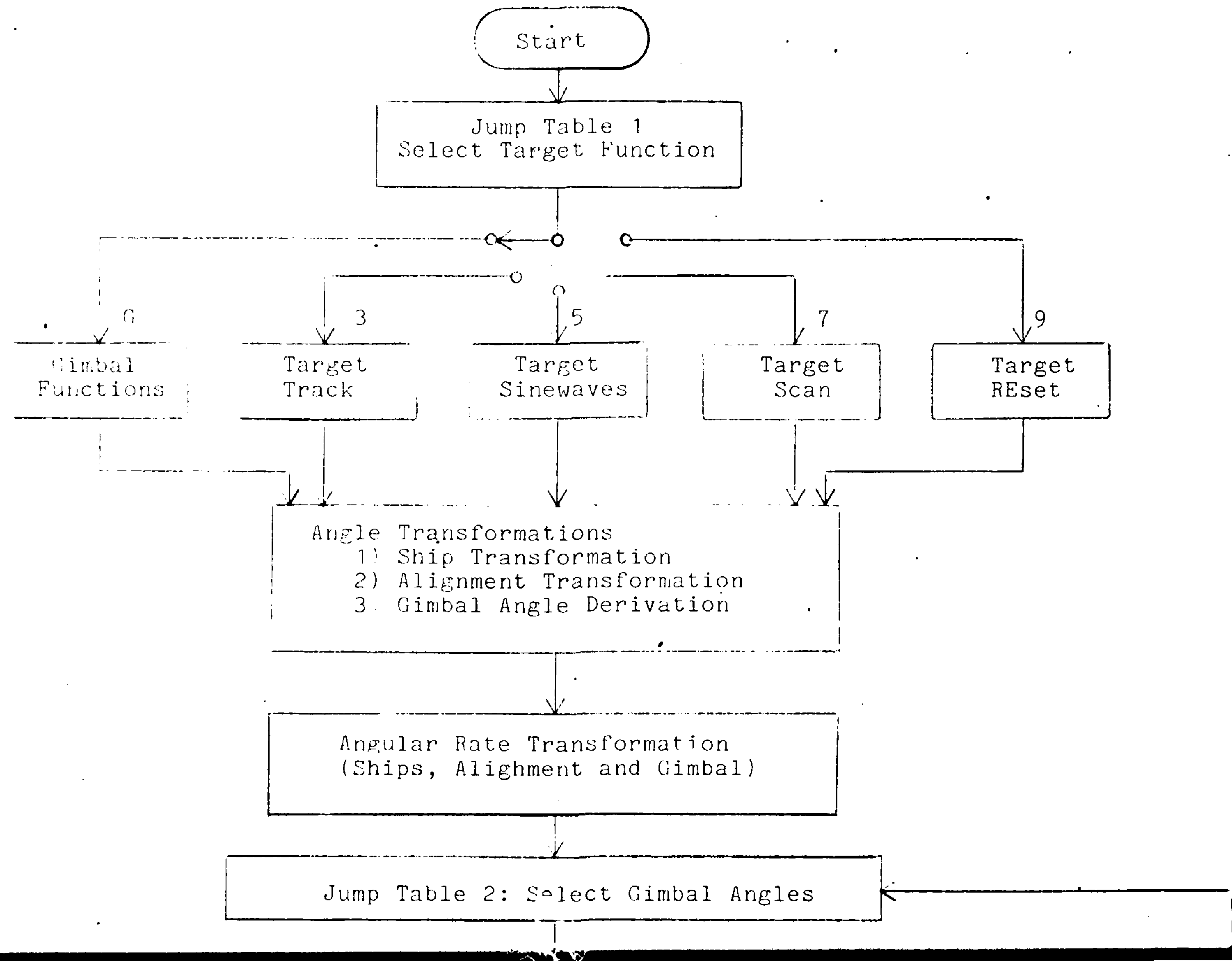
4.1 DMAR ANTENNA CONTROL SOFTWARE

Section 2 of this report describes the functional approach used by the Navtrol Company in providing control of the NRL's DMAR Antenna. This description pretty much defines in the functional sense, the contents of the program. However, it does not define the program breakdown or the order in which each of the calculations are made. This is defined by Figure 4.1-1, which is a flow chart for the DMAR Antenna Control Software, and by the program itself. Note that the flow chart closely follows the functional description given in Section 2.

A source listing for the All Digital Controller software programs developed for control of NRL's DMAR Antenna and associated functions is provided in Appendix C of a separate document entitled "Description of the All Digital Controller for NRL". Table 4.1-1 defines the different programs, sub-routines and other information contained in that Appendix. In general these programs are well supplied with descriptive comments, including equations, to help in their understanding

The first listing in the Appendix is the main program used for control of NRL's DMAR Antenna. The next set of listings is for the sub routine BOXSCN which contain the software logic for deriving the commands for performing a box shaped scan about any of the eight selectable targets. The NRL Library contains other sub routines used in NRL's application, such as one for deriving sine and cosine signals for controlling the antenna, one for

FIGURE 4.1-1: NRL DMAR Antenna Control Program Flow Chart



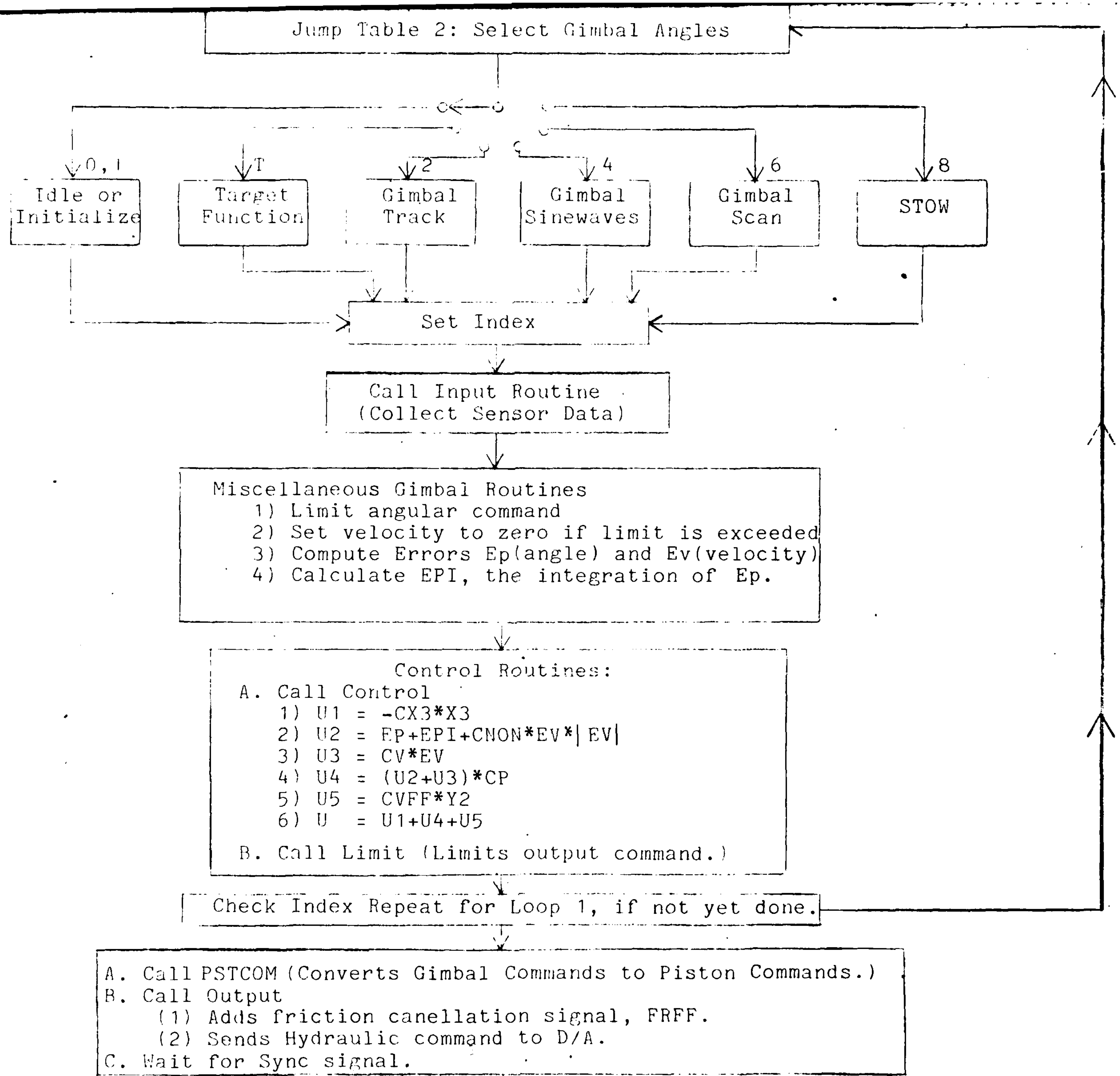

Jump Table 2: Select Gimbal Angles
0, 1
T
2
4
6
8
Idle or Initialize
Target Function
Gimbal Track
Gimbal Sinewaves
Gimbal Scan
STOW
Set Index
Call Input Routine
(Collect Sensor Data)
Miscellaneous Gimbal Routines
1) Limit angular command
2) Set velocity to zero if limit is exceeded
3) Compute Errors Ep(angle) and Ev(velocity)
4) Calculate EPI, the integration of Ep.
Control Routines:
A. Call Control
1) U1 = -CX3*X3
2) U2 = EP+EPI+CNON*EV*|EV|
3) U3 = CV*EV
4) U4 = (U2+U3)*CP
5) U5 = CVFF*Y2
6) U = U1+U4+U5
B. Call Limit (Limits output command.)
Check Index Repeat for Loop 1, if not yet done.
A. Call PSTCOM (Converts Gimbal Commands to Piston Commands.)
B. Call Output
(1) Adds friction canellation signal, FRFF.
(2) Sends Hydraulic command to D/A.
C. Wait for Sync signal.

TABLE 4.1-1

Program Listings Provided to NRL*

1. ADC Control for NRL's DMAR Antenna:

   Main Program; 23 pp.

2. Sub-routine BOXSCN; 4 pp.

3. NRL Library (Other Sub-routines); 6 pp.

4. ADC Data Assignments

   a) ADC Parameter Address Table; 1 pp.

   b) ADC I/O Assignments and ADC Data Memory Organization; 6 pp.

5. Symbol Table (Location of Parameters in Data Memory); 3 pp.

6. Diagnostic Program; 14 pp.

*Contained in Appendix A of "Description of the All Digital Controller for NRL")

defining the sine or cosine of an angle, one for double precison multiplication, and etc..

The ADC Data Assignments are not too useful except for the I/O assignment table which indicates the address for each of the five IO functions for both axes. Note that the data assignments are broken down into RAM and PROM assignments, separating the variables from the parameters which are expected to be constant. Of course in the development system supplied to NRL, all these constants are contained in RAM.

Perhaps the most useful table in the listing is the "Symbol Table" which among other things defines the locations of parameters in Data Memory. All of the symbols used in the program are defined in this table, not just the symbols which represent Data Memory locations. For example, locations in Program Memory which are provided with names or "symbols" also appear on the symbol table. The location corresponding to each symbol is provided.

The last item provided is a Diagnostic Program which excercises every instruction of the All Digital Controller with the exception of the I/O instructions. The I/O instructions are excluded because they require external connections in order to properly evaluate their functional operation. This is general purpose program previously developed not using NRL funds.

Table 4.1-2 provides a listing of the sub-routines included within NRL's package. Many of these sub routines are standard and utilized in various control systems which in turn utilize the All Digital Controller.

TABLE 4.1-2

NRL CONTROL SOFTWARE SUBROUTINES

1. SINPUT: Sensor Input Routines (Differential Pressure, Tachometer and Encoder).

2. OUTPUT: Formats and sends out commands to a D/A converter, providing analog control inputs to the Hydraulic System.

3. CONTRL: Contains the Control Algorithms.

4. CXFORM: Obtains sine and cosines for measured gimbal angles.

5. PSTCON: Calculates constants for conversion from gimbal rates to Piston rates and performs the conversion.

6. TARGMV: Provides Target integration for all 8 Targets.

7. TARGTK: The Target to be tracked is selected.

8. RESET: Resets target angles to original values.

9. GINIT: Initializes gimbal angles and velocities to the selected values.

10. GTRK: Provides gimbal angle integration.

11. BOXSCN: Defines angles and velocities required to perform desired "Box" around the selected target or gimbal angle.

12. SCINT: Initialization Routine for BOXSCN.

13. SIGNAL: Defines angles and velocities for sinewaves in each axis about the selected target or gimbal angle.

14. LIMIT: Limits the magnitude of a double precision number to a single precision limit.

15. DPMUL: Performs double precision multiply.

16. INDXØ: Sets index to zero.

17. CKIX2: Compare Index with ID2, a word in memory and sets CCR. (CKIX is similar).

18. SIN: Calculates the sine of an angle in the accumulator. (MSB after sign bit = 90 deg.).

TABLE 4.1-2 (Cont.)

19. COS: Calculates the cosine of an angle in the accumulator (MSB after sign bit = 90 deg.).

20. ALIMIT: Limits the amplitude of a sine wave according to frequency.

21. RAMPT: Calculate ramp function for target.

22. RAMPG: Calculates ramp function for gimbal.

All of the software has been provided to NRL on 5.25" floppy diskettes utilized in the Navtrol's Servo Development System. Included within the document entitled "Description of the All Digital Controller for NRL" is a section entitled "Operating Procedures" which defines how to use NRL's System and also how to use standard Navtrol software including the diagnostic program.

4.2 FRONT PANEL COMPUTER SOFTWARE

4.2.1. SYSTEM CONTROL AND MONITORING FROM THE FRONT PANEL

A Z80 micro processor controlled front panel has been included in the All Digital Controller to provide the human operator access to the Digital Controller Processor Unit. The Front Panel Computer and its software provides full programmability for all front panel functions without affecting the ADC Processor Unit program.

The Front Panel and its controls can be seen on the right side of Figure 1-3 in the Introduction to this report. The function switch located on the right hand side of the Front Panel provides capability of selecting 8 modes of operations. Two keyboards on the left hand side provide access to every word in both Program Memory and Data Memory. Two 6 digit hexidecimal displays, capable of displaying either in hexidecimal or decimal format, are provided. Seven discrete lights define the status of the Front Panel Computer. Using the Front Panel controls every word in either Program or Data Memory can be monitored and/or changed. If the program and data has previously been programmed into EPROMS in the Front Panel Computer, these can

automatically be loaded into the All Digital Controller directly from the Front Panel without using the CRT keyboard or diskette units. This capability minimizes the equipment required to be located with the antenna to be controlled. The functions available from the Front Panel are listed and briefly described on Table 4.2-1.

4.2.2 NAVTROL'S MONITOR PROGRAMS, SMONITOR AND PMONITOR

4.2.2.1 SMONITOR PROGRAM

Compared to front panel, use of the CRT, keyboard and disc drives along with Navtrol's monitor software programs, provides much more complete and efficient control and monitoring of the All Digital Controller. In particular, the extensive functions available on the NRL System are available only through use of one of the monitor programs. Either monitor program requires the full Software development sytems capability (except the the printer) including CRT, keyboard and disk drive units. The SMONITOR program is used when serial communication is being used between the Front Panel Computer and the All Digital Controller Processor Unit. Use of the 2 MHz Serial Interface allows the ADC Processor Unit to be located remotely from the Front Panel Computer and/or the rest of the Software Development System.

The "Full Menu" for the SMONITOR programs displayable on the CRT, provides a basic description of the functions available using the SMONITOR program. An abbreviated menu is also available to speed up function selection for those already familiar with the functions available. The "Full Menu" is as follows:

NAVTROL SERIAL COMM. MONITOR PROGRAM VERSION 3.1, 1982

TABLE 4.2.1

FUNCTION SWITCH POSITIONS DESCRIPTION

1. EXT - This position permits control of the FP computer from the CRT keyboard, not from the Front Panel.

2. TEST - Automatically loads diagnostic program into ADC Processor and commands it to run. Lack of Fault light identifies satisfactory operation. (Not presently implemented.)

3. LOAD DATA - Allows loading ADC Processor Unit Data Memory from PROMS in the FP Computer.

4. LOAD PROG - Allows loading ADC Processor Unit program from PROMS in the FP Computer.

5. MAN DATA - Used for reviewing or changing large blocks of data in ADC Processor Unit Data Memory. Automatically sequences to next Data Memory location after data is entered.

6. MAN PROG - Allows manual changes in the ADC Processor Unit program using the Front Panel Keyboard and Displays.

7. STBY - The standby position is used for loading or changing constants and/or initial values in Data Memory and otherwise preparing for control.

8. OPER - The Operate function places the ADC Processor Unit in the "Operate" mode for normal operation.

MEMORY OPTIONS:

    M-MEMORY MONITOR. (MP=PROGRAM, M1=DATA1, M2=DATA2.)
    L-LOAD DATA OR PROG MEMORY. (LP=PROG., L1=DATA1, L2=DATA2.)
    S STORE DATA OR PROG MEMORY (SP=PROG., S1=DATA1, S2=DATA2.)
    T TEST MEMORY (TP=PROG., T1=DATA1, T2=DATA2.)

FUNCTION SELECTION OPTIONS

    P-PARAMETER SELECTION FOR FUNCTIONS
        P1=TARGET DIRECTION PARAMETERS.
        P2=GIMBAL DIRECTION PARAMETERS.
        P3=SPECIFIC FUNCTION PARAMETERS
    X,Y,B-FUNCTION SELECT (XIJ=X-AXIS, YIJ=Y-AXIS, BIJ=BOTH AXIS.)
        I=NO. OF THE SELECTED FUNCTION
            0=IDLE
            1=INITIALIZATION
            2=TRACK GIMBAL
            3=TRACK TARGET
            4=SINE WAVE INTO GIMBAL
            5=SINE WAVE INTO TARGET
            6=SCAN GIMBAL
            7=SCAN TARGET
            8=STOW
            9=RESET TARGET DIRECTION ANGLES
        J=DATA SELECT NUMBER (REFER TO "P")

ADC MODE SELECT

    O-OPERATE
    C-CLEAR ADC

Options "M1" and "M2" allow you to manually insert data or monitor data from Data Memory 1 or Data Memory 2 respectively. Option "MP" allows manual insertion, monitoring or editing of program instructions. The LP, L1 or L2 options allows loading of Program or Data Memories automatically from diskettes. Both program and data must be located on the same diskette with SMONITOR. The SP, S1 or S2 options permit automatically storing the contents of Program or Data Memory within the ADC onto diskettes. Note that the data or program stored from the ADC will overwrite a previously stored program or data on the diskette. Through the options discussed in this paragraph, the program or data can be loaded, edited and stored back onto a diskette.

Options TP, T1 or T2 are utilized for testing Data or Program Memory. Through these options random entries, a single constant or two different constants can be utilized to repetitively test all locations in either Data and Program Memory.

Options are also provided for selecting the particular function the All Digital Controller is to perform. These functions are listed on the Option Table. As indicated, tracking, sine wave and box scan functions can be commanded into either one axis at a time or both axes. These functions can be commanded about 8 different target directions. A particular set of parameters, such as direction, scan width, etc., pertaining to the desired function is indicated by the data select number.

Prior to their selection, the desired parameters must be entered into a file, accomplished through the "P" option. To facilitate selecting a particular function, special "function" keys are provided at the top of the keyboard. Pressing the appropriate function key, the HEX keypad (twice) and the Return Key selects a desired function. Likewise, going from one "target" to another is accomplished in the same manner. Additional details on function selection, parameter selection, and other options is provided in Section 4.0 of the document entitled "Description of the All Digital Controller used for NRL's DMAR Antenna Control."

Finally, the All Digital Controller can be commanded in either the "Operate" or "Clear" (non operating) mode by pressing either "O" or "C" and"Return." A "Clear" key is also provided at a convenient top location of the keyboard to permit rapidly placing the All Digital Controller in a non-operating mode should

a problem arise. ("Return" is also required.)

4.2.2.2 PMONITOR PROGRAM

4.2.2.2.1 GENERAL DISCUSSION

Use of the PMONITOR Program implies operation in the parallel IO mode. To operate in this mode, a "Parallel Interface Board", supplied to NRL with the system, must be installed in the ADC (All Digital Controller). In addition, to use the parallel I/O in the "Clear" or non-operative condition requires that a switch on the Parallel Board be in the "Parallel" position. This switch position enables parallel communication and disables serial communication in the "Clear" mode. With either switch position both can still function in the "Operate" mode. The "Full Menu" for the PMONITOR is as follows:

```
     NAVTROL PARALLEL COMM. MONITOR PROGRAM VERSION 3.1, 1982
-----------------------------------------------------------------
MEMORY OPTIONS;
     M-MEMORY MONITOR.  (MP=PROGRAM, M1=DATA1, M2=DATA2.)
     L-LOAD DATA OR PROG MEMORY.  (LP=PROG., L1=DATA1,
     L2=DATA2.)
     S STORE DATA OR PROG MEMORY (SP=PROG., S1=DATA1,
        S2=DATA2,)
     T TEST MEMORY (TP=PROG., T1=DATA1, T2=DATA2.)
FUNCTION SELECTION OPTIONS
     P- PARAMETER SELECTION FOR FUNCTIONS
               P1=TARGET DIRECTION PARAMETERS.
               P2=GIMBAL DIRECTION PARAMETERS
               P3=SPECIFIC FUNCTION PARAMETERS
     X,Y,B-FUNCTION SELECT(XIJ=X-AXIS,YIJ=Y-AXIS,BIJ=BOTH AXES.)
               I=NO. OF THE SELECTED FUNCTION
                    0=IDLE
                    1=INITIALIZATION
                    2=TRACK GIMBAL
                    3=TRACK TARGET
                    4=SINE WAVE INTO GIMBAL
                    5=SINE WAVE INTO TARGET
                    6=SCAN GIMBAL
                    7=SCAN TARGET
                    8=STOW
                    9=RESET TARGET DIRECTION ANGLES
               J=DATA SELECT NUMBER  (REFER TO "P")
```

```
DATA COLLECTION OPTIONS
     I-INITIALIZE DATA COLLECTION
     E-EXECUTE DATA COLLECTION
     D-DSPLAY DATA
     D1-PLOT THE FIRST SET OF CURVES  (GRAPHIC MODE ONLY)
     D2-PLOT THE SECOND SET OF CURVES (GRAPHIC MODE ONLY)
ADC MODE SELECT
     O-OPERATE
     C-CLEAR ADC
```

Each option which the Serial Monitor also contains, is exactly the same when using PMONITOR as for SMONITOR, and the descriptions are not repeated. However, the Data Collection Options are available only in the parallel mode and are described in paragraphs which follow.

4.2.2.2.2 DESCRIPTION OF THE DATA COLLECTION OPTIONS

4.2.2.2.2.1 OPTIONS AVAILABLE

Selecting "I" of the data collection option results in the following CRT display:

```
?I
ENTER THE FUNCTION NO:
1 - SELECTION OF DISPLAY OR STORAGE DEVICE
2 - DEFINE DATA TO BE TRANSMITTED
3 - ENTER THE ADDRESSES OF DATA TO BE DISPLAYED
4 - ENTER DATA COLLECTION AND PLOTTING TIMES
5 - DEFINE FILE FOR GRAPHICS PARAMETER SETS
6 - DEFINE GRAPHICS PLOTTING INFORMATION
7 - EXIT THE INITIALIZATION MODE
```

Typing "1" and "Return" results in the following prompt permitting selection of the output device;

ENTER THE OUTPUT DEVICE (P/C/D/G) C-)

(P = Printer, C = CRT, D = Disk, G = Graphics)

The first 3 or these are for making lists of data taken during a run. As indicated, the data list can be printed out by the printer, displayed on the CRT, collected on a diskette or presented as X-Y plots (graphics form) on the CRT. Data of

several parameters can be collected at each sampling instant. These samples can then be presented as functions of time. Note that for the lists, the data is collected and presented in Hex format. The graphics routine presents plots with decimal coordinates.

4.2.2.2.2.2 GRAPHICS TERMINAL OPTION

In the graphics option data from as many as four parameters are collected at each sample instant and stored in the Front Panel Computer. Upon request these data sets can be displayed as time response curves on a graphics CRT. Two sets of two curves each are possible. Frequency responses, step responses and other responses can be readily monitored using this capability. However, in order to properly display the data, the graphics routine must contain data on the scale factor of the parameter as stored in the ADC, defined by the MSB of the particular parameter, the amplitude of the curve and the length of time for which the data is to be taken and presented. The graph can be duplicated on the Navtrol printer for use in reports or later reference.

To be useful at a later data the graphs must be adequately labeled as to the plotted parameter and the scale factor of each axis. Entering the amount of data for several curves can be time consuming. To facilitate the plotting routines Navtrol has stored data on the most significant NRL parameters in Navtrol's Application Disk for NRL. Forty different "curve sets", numbered 0 to 39, can be stored in this file.

The parameters sets presently defined within the NRL system are listed on a table provided in a separate document. From the

list of parameters on that table, a parameter set can be selected for each of the 4 curves, resulting in automatic initialization of the various curve parameters. Time length and amplitude of the vertical axis may not be that desired by the operator and he has the option of altering these and other parameters as he desires. Even though changes to a couple of parameters is likely, initializing the curves from the "curve set" file saves considerable time, since labeling and other time consuming tasks are taken care of.

SECTION 5
SYSTEM RESULTS

5.1 SYSTEM INTEGRATION

5.1.1 INTERFACE CHECKOUT

5.1.1.1 A/D CONVERTER

Two identical interface units were specially designed for the DMAR Control System. These are described in Section 3.3. The A/D converter is described in Section 3.3.6. The input to the A/D can be either the tachometer signal or the differential pressure measurement. Initial check out of the A/D converter consists of feeding appropriate DC signals through either the tachometer input connection or, simultaneously, into the two pressure inputs. The A/D converter provides an offset reading so a bias must be subtracted from it within the ADC Processor Unit to obtain the correct reading. Adjustments were made until correct readings were obtained within the Processor Unit corresponding to the applied positive or negative voltages. Note that the circuit was checked front to back, all the way from the input analog signals into the appropriate connectors to reading out the digital word representing the measurement within the ADC Processor Unit.

5.1.1.2 ENCODER INTERFACE

NRL provided Navtrol with an encoder mounted on a breadboard with its own power supply. The encoder output was fed into the encoder interface and read back into the ADC Processor Unit. The shaft of the encoder was rotated in known increments and the digital angle read within the Processor Unit, providing a front

to back check of the total interface.

5.1.1.3 D/A FUNCTIONS

The Tach Conversion function requires that the magnitude of the analog signal from the tachometer be multiplied by a digital signal. A sinewave signal was substituted for the tachometer signal. The output from the D/A converter amplifier was monitored while the digital signal from the ADC Processor Unit was varied from zero to max. At the frequencies of interest very little feed through was seen when the digital signal was set to zero and the output was approximately equal to the product of the two terms. The multiplication was checked to approximately 1% accuracy which was felt to be adequate for this application.

The hydraulic system control input D/A circuitry was checked by commanding the appropriate output from the ADC Processor Unit and checking the corresponding analog signal to see if it was correct. No problems were encountered here.

5.1.1.4 VALVE SIGNAL LEAD SHAPING CIRCUIT

As indicated in the description contained in Section 2, the valve signal lead shaping circuit simulates a second order system. It's response was checked by running a frequency response with a func•ion generator. No particular problems were encountered in the initial testing. At NRL the test consisted of performing a frequency response on the hydraulic valve circuitry by monitoring the demodulated output indicating spool position. The model within the valve signal lead shaping circuit was adjusted so that it roughly corresponded to the response of the valve. By feeding back additional damping and position signals

the input into both the modeled system and the actual hydraulic valve was altered. The approach definitely increased the bandwidth between the input to the shaping network and the output of the valve compared to just the response of the valve. Later, the valve was readjusted so that the model no longer matched. At that time the valve signal lead shaping circuit was bypassed and at present is no longer being used. Criticality of the approach to variations of parameters such as might be expected with temperature and age, was not established.

5.1.2 INITIAL SYSTEM INTEGRATION EFFORTS

The fabrication of digital control system for the DMAR antenna was completed, the system delivered and initially integrated with the antenna and hydraulic system during February, 1982. Although the basic capability to control the antenna was demonstrated several shortcomings were noted. The encoder data was unreliable with occasional jumps observed in the data which were not physically realizable by the antenna. Problems were encountered in the pressure transducers with drift and at least one outright failure. Problems were encountered with the ADC Processor Unit software. To overcome these, all the transformations and certain other functions were bypassed. Even with the shortcomings, it was demonstrated that the system could be commanded to follow sine waves in both axes either independently or simultaneously. The capability to collect system data using the Servo Development System and plot response curves proved most beneficial. The effort was halted after one week with the basic goal of being able to control the antenna and point it in any direction being accomplished.

Additional tests were ran in June, 1982 after NRL had corrected the encoder problems and adjusted performance of the hydraulic valves. These tests showed that the resulting system response was much smoother then previously observed. This effort required only one day as the program corrections had not yet been completed.

5.1.3 FINAL INTEGRATION

The software program was reorganized and many new functions added before the final integration effort. Navtrol developed a special communication board which allowed one ADC Processor Unit to communicate with another through the serial communications links. At Navtrol one ADC Processor Unit was used to simulate the antenna, hydraulic system and sensors while another provided control. This enabled the software program to be was checked out prior to returning to NRL. Changes in the program accomplished during this period included reinserting the transformations, pretty much in their original format. However, several linking routines were corrected so that the transformations could be properly utilized. Software routines were written which allowed for 8 moving targets to be inserted in the system, with the system capable of pointing the antenna at any of the 8 targets upon command by the operator. In addition, routines for conically scanning the antenna and performing box scans about any point in space, including the 8 moving targets, were written and debugged. The capability for better control of the antenna, using the antenna system simulation, was also demonstrated.

The programs utilized in the Z80 "Front Panel Computer" were modified so that data required to define the eight targets and the function to be performed by the system could be expediciously entered by the operator. Routines were written to store parameters of the graphs of the response of the most significant parameters, such as angles and angular velocities, etc., in a table. Appropriate titles, scale factors and data locations were all stored in this table. This greatly expedited the selection and labeling of curves to illustrate system performance.

Final system integration was undertaken in September, 1982. with one week provided for this effort. The new system software was delivered and although some problems were encountered it was apparent that the system goals for functional capability had been met. Initially, a problem in the ADC Processor prevented the controlling of both axis simultaneoulsy using a new more efficient routine for reading the various sensors. (The old routine worked fine.) This problem was difficult to diagnose and required considerable time. It was associated with the micro program FPLA which was updated to correct the deficiency.

Time was also spent debating if the complex "half angle" transformation of beam to gimbal angles had been correctly implemented and how to test this function. The conclusion was that the transformation was correct as implemented.

5.1.4 CONTROL GAINS

Figure 5.1-1 duplicates Figure 2.4-2 of Section 2 of this report. It is provided here for convenience in understanding the control gain values. In addition to the gains shown, there is a gain of 256 between the summing point of U and the input to the

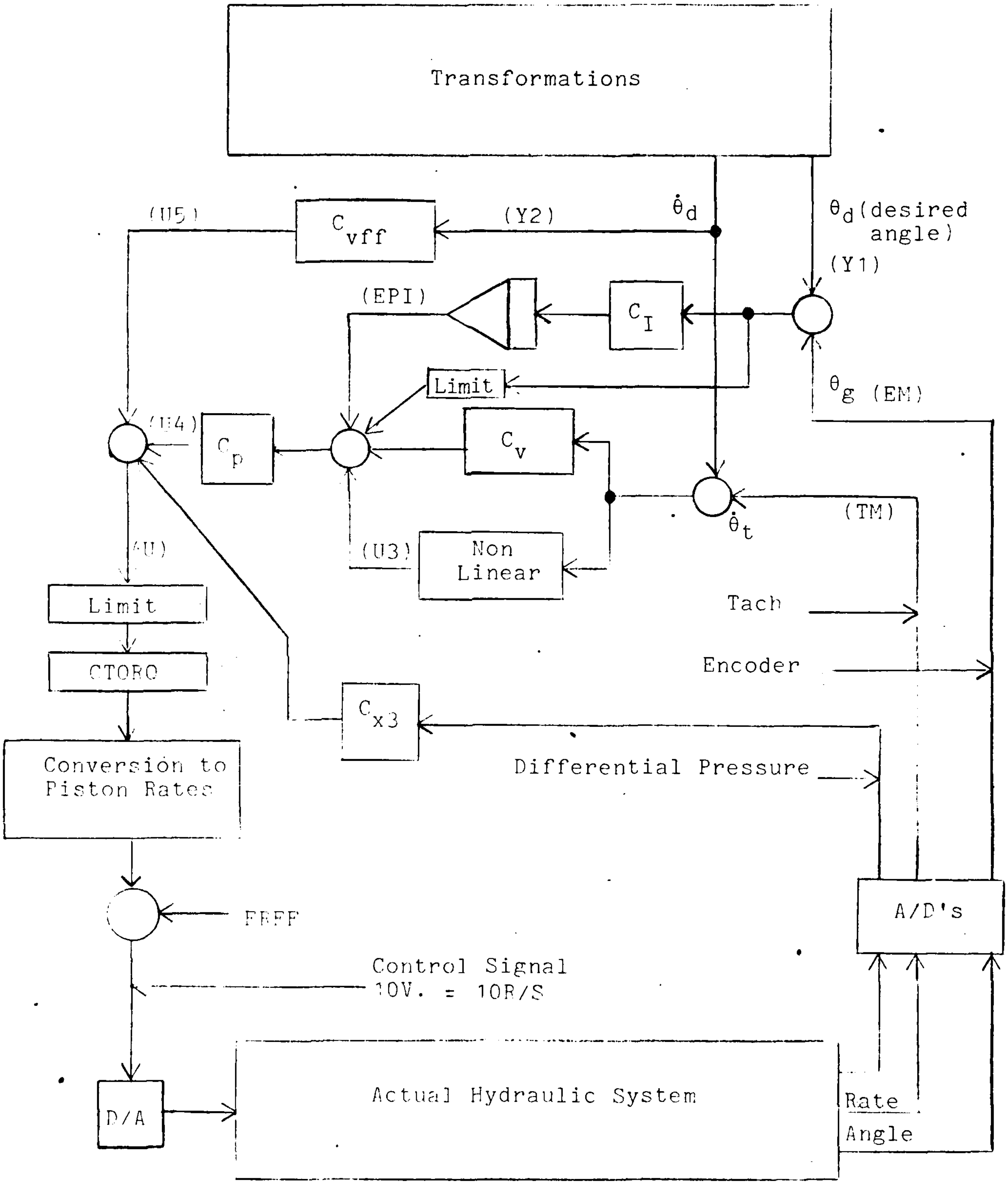


FIGURE 5.1-1: Digital Control Functions

function "Conversion to Piston Rates," which has a gain of .99 when both gimbal angles are zero.

The method for calculating approximate gains is illustrated on Table 5.1-1. As indicated there, the first step is to convert to decimal equivalents the hexidecimal gain values, used within the control software, using .5 as the MSB. An equation is then provided for obtaining the actual gain value of the control gains which connect to the output. Note that the gain C_V does not tie into the output and therefore the equation does not apply.

Part B of Table 5.1-1 provides the approximate actual gains utilized during various performance runs. Since the hydraulic system provides velocity proportional to the applied voltage input, the gains are defined in terms of degrees/second of system velocity per unit of measure of the applied parameters. The nominal gain values for the system are; C_p = 21.2, C_V = 0.0, C_{X3} = 0.0, C_{VFF} = 1.05 and C_I = to 0.0. The selection of nominal gains was not clear cut and sufficient runs were not made to assure that these values provide the best performance under all conditions. For example, even the selection of the sign for C_V for best performance was not clear cut. This is discussed further with respect to particular system response runs in Section 5.5.

Selecting C_{VFF}, the feed forward velocity gain, was accomplished by putting velocity steps into the system and adjusting C_{VFF} until the error was minimum. The lower the value of C_p the easier it is to adjust C_{VFF}. Note that C_{VFF} is an open loop, feed forward gain, which is not greatly affected by the

TABLE 5.1-1: Control Gains

A. Gain Calculation (Only for Gains to the Output.):

1) Calculate decimal equivalent of the Program Gains (Gpr) from their hexidecimal value using MSB = Ø.5.

2) Ga = Gpr * 256 * Ø.99 * MSB(Output) / MSB(Parameter)
where: Ga = Actual Gain
MSB (Output) = 5 R/s = 286.5 deg./sec.
MSB (Velocity) = 36Ø deg./sec.
MSB (Angle) = 9Ø deg./sec.
MSB (Pressure) = 5ØØ PSI

B. Gain Values

Parameter	Program Value (Hexidecimal)	Approximate Actual Gains
Cp	Ø24Ø	14.2 deg./sec./deg.
Cp	Ø36Ø	21.3 deg./sec./deg.
Cp	Ø48Ø	28.4 deg./sec./deg.
*Cv	Ø2ØØ	.ØØ39 deg./deg./sec.
*Cv	FAØØ	-.Ø117 deg./deg./sec.
Cx3	FCAØ	-3.82 deg./sec./PSI
CVFF	ØØAB	1.Ø5 deg./sec./deg./sec.
CI	ØØØØ	ØØØØ deg./deg.

*Note that velocity error is multiplied by Cv and Cp in series.

value of the error feedback gains. The obvious value for C_{VFF} is 1.0 deg./sec./deg./sec.. The value obtained empirically, 1.05, is well within the accuracies either in the method for selecting the gain or in the hydraulic system gain.

C_{X3} is a feed back gain from differential pressure into the input. This inner loop gain affects primarily high frequency performance and was no doubt affected by digital time delays. It was also affected by mechanical and hydraulic resonances whose behavior most likely varied with antenna position. Another value, other than zero, appeared to provide slightly better performance but the system showed a tendency to oscillate at 35 to 40 Hz at a very low amplitude. The oscillation was visible only on the differential pressure measurements.

A negative value of the velocity gain which actually decreased the damping at the frequencies of interest, also appeared to improve the step response of the system. A hydraulic system of the type used here has inherent internal velocity feedback which provides damping. Although velocity step responses ran with $C_V = 0$, showed the velocity response to be lightly damped, the position step response was over damped and the negative value of C_V reduced the time required to step from one pointing direction to another. Increasing C_V in the positive direction increased the damping on the step response further and increased the travel time. Trying to compensate for the increased damping by increasing C_p appeared to decrease the stability margin.

Finally, although the capability for integral gain was

provided, for the performance runs that were recorded integral gain appeared to provide no improvement and so the gain was set to zero and left there.

It is probable that some additional improvements in system performance could be accomplished by further optimization of gains. Just how much is not known. Even better performance could most likely be obtained by modeling the control system within the computer and obtaining additional feed back in this manner for shaping the responses. This approach has been previously utilized by Navtrol in many applications and advocated for this one. However, such an approach would require time and funds and the improvement may not equal that provided by improving the hydraulic and mechanical system. The recommended approach, of course, is to do both.

5.2 ADC PROCESSOR CAPACITY

5.2.1 PROGRAM RUN TIME

Table 5.2-1 illustrates the present utilization of ADC processor capacity. As indicated, the total run time is approximately 1400 micro seconds out of 1953 micro seconds available. Thus, there appears to be approximately 550 micro seconds for additional tasks. However, most of this 550 micro seconds is utilized in transferring data to the Front Panel or some other Computer for measuring and plotting system performance. The amount of time required is a reflection of the speed of the Front Panel Computer. The fact that the ADC Processor Unit is tied up during this period is due to a deficiency in the design of the parallel interface between the Front Panel Computer and the ADC. If the parallel interface was

TABLE 5.2-1

PRESENT COMPUTER REQUIREMENTS FOR NRL

A. PRESENT PROGRAM RUN TIME (APPROX.)	
1. TRANSFORMATIONS, ETC.	650μs
2. CONTROL PROGRAM	600μs
ACTUAL PROGRAM RUN TIME	1250μs
3. I/O TRANSFER TIME (10 CALLS)	150μs
TOTAL RUN TIME	1400μs
PRESENT SAMPLING RATE	$512^{S}/_{S}$
TIME	1953μs

B. MEMORY REQUIREMENTS	AVAILABLE	USED
1. PROGRAM MEMORY	4K	1.3K
2. DATA	2K	1K

redesigned to include storage of multiple words, the ADC could transfer the data from the interface all at once, without waiting for the FP or other computer. It is felt that a reduction of approximately 100 to 1 in the time required within the ADC Processor Unit for making this transfer could be accomplished. Doing this, would allow the 550 micro seconds to be made available for additional processing in the ADC, as required. In addition, the FP or other computer would have almost the entire sampling interval to send or receive data from or to the interface, improving the efficiency here also.

The IO transfer calls require 150 micro seconds. The ADC Processor has the capability for making these calls while continuing to process other signals. This capability is not utilized in the NRL program. By integrating the calls into the program in such a way as to utilize this capability to continue processing while the information is being brought back from the interface units, almost all of this time could be utilized for other computational requirements.

Review of the program reveals that there are several areas where program efficiency could be improved using present knowledge. For example, double precision routines are used in several areas where it is doubtful that they are necessary. It is estimated that revising the program to make it more efficient would result in reducing the run time by several hundred micro seconds. Combining this with the integration of the IO transfers could reduce processor time utiliziation to between 50 and 60% of the total time available. This processor time could then be

AD-A125 812 ANTENNA DIGITAL CONTROL FOR THE DIRECTED MIRROR ANTENNA RADAR (DMAR)(U) NAVTROL CO DALLAS TX 15 FEB 83 N00173-80-C-0425 2/2

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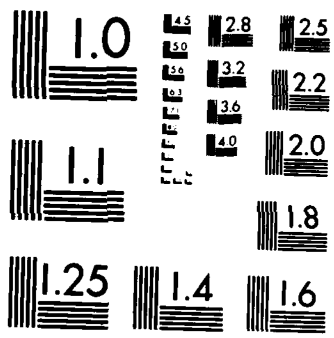

MICROCOPY RESOLUTION TEST CHART
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used for other functions such as performing transformations for presentation of data on PPI scopes or other real time displays.

Additional program time could also be made available by performing the transformations at a lower sampling rate than required for the control portion of the program. Appropriate interpolation of the commanded gimbal angle and velocity could alleviate the degradation due to the increased samping period.

5.2.2. MEMORY REQUIREMENTS

As indicated on Table 5.2-1, 4K of program memory is available with approximately 1.3K utilized. Even this small utilization could be reduced by some of the same approaches mentioned in the previous section for reducing program run time.

Data memory utilization is less than 1K of the 2K available. This could be reduced significantly by combining various temporary storage locations. The additional temporary storage locations are useful in debugging the program or locating problems during system integration, since it is easy to read out intermediate computational points by accessing the appropriate locations in Data Memory, However, they serve little use in a final system. Reducing memory reduces power and increases reliability in a final system configuration.

5.2.3 SYSTEM SIZE AND POWER

System sizes were discussed in Section 3 of this report. The Digital Controller Processor Unit requires 32 watts at 5 volts in its present form which utilizes all RAM memory. Use of a combination of RAM and PROMS, with the same total capacity, would reduce the power to approximately 26 watts. By implementing only the memory required in the final system the total power could

probably be reduced to approximately 20 watts, depending of course on the amount of memory required in a final system configuration. The power in the Processor Unit is broken down in more detail in the "Description of the All Digital Controller" provided as a separate document to NRL.

The Front Panel Controller is generally not considered a part of the Antenna Control System but rather a Servo and/or Software Development and Monitoring System. The full Development System requires approximately 5.1 amp at 8 volts, .5 amp at +16 volts and .1 amp at -16 volts. The Front Panel Computer boards all contain regulators to obtain the required voltages at the board level. The "Description of the All Digital Controller" document also provides a breakdown of the power in the Front Panel Computer.

The NRL Interface Units received their power directly from the main unit of the All Digital Controller. Voltages supplied are 8 volts, +16 volts, and -16 volts. Regulators within the interface unit regulate these voltages down to 5 volts and + and - 12 volts, all D.C., for use within the interface unit. There are no devices within the interface unit that require significant power and power requirements for the Interface Units are small. Since Interface Unit power was not considered a problem, definitive measurements of power utilized by the them were not made.

5.4 SYSTEM DEMONSTRATION

A system demonstration was provided by NRL and Navtrol engineers for interested parties. This demonstration consisted

of the tests indicated on Table 5.4-1. At the end of this table, brief descriptions of the angles referred to in the table are provided. Further discussion on the angles and transformations is contained in Section 2.0. Referring to this table note that the STOW function is simply driving the antenna to the STOW position, presently defined with both gimbal angles at zero. A different STOW position could be easily selected, if desired. Tests Number 2 demonstrated the capability of the control sytem to point the antenna using any of 4 different sets of gimbal angles upon command from the operator. Pointing is a sub-set of the "Track Function," which, along with other functions, is described in Section 2.5 of this report. The four sets of gimbal angles are indicated on the Table.

A function is selected by simply typing the function number indicated and hitting "Return." The B in the function number indicates that both axes are being controlled. The first number indicates the type function being commanded, gimbal track in this case. The last number indicates the direction about which a function is to be performed. In this case it indicates a set of gimbal angles and velocities previously assigned. For this system demonstration the velocities associated with the gimbal angles about which the functions were performed were always set to zero. Each angle could have been independently given a velocity, if desired.

The fourth test, B64, commanded a gimbal scan centered about a set of gimbal angles. The "Scan Limit" is analogous to sinewave amplitude (to be discussed shortly) in that it

TABLE 5.4-1: SYSTEM DEMONSTRATION

Test No.	Function No.	Function Name	Description
1.	STOW	STOW	Drive both gimbal angles to zero.
2a.	B20	Gimbal	Theta = -15 deg., Phi = -15 deg.
2b.	B21	Track	Theta = +15 deg., Phi = -15 deg.
2c.	B22		Theta = +15 deg., Phi = +15 deg.
2d.	B23		Theta = -15 deg., Phi = +15 deg.
3.	STOW	STOW	
4.	B64	Gimbal Scan	1) Scan Center at Theta = 0 deg. and Phi = 0 deg.. 2) Velocity for both axes = 45 deg./s. 3) Scan limits = 15 deg. for both axes.
5.	B44	Gimbal Sinewave	1) Frequency = 1 Hz. 2) Theta Amplitude = 35 deg. 3) Phi Amplitude = 0 deg. 4) Scan Center at Theta = 0 deg. and Phi = 0 deg.
6.	STOW	STOW	
7.	B45	Gimbal Sinewave	1) Frequency = 1 Hz. 2) Theta Amplitude = 0 deg. 3) Phi Amplitude = 20 deg. 4) Scan Center at Theta = 0 deg. and Phi = 0 deg.
8.	STOW	STOW	
9.	B46	Gimbal Sinewave	1) Frequency = 1 Hz. 2) Theta Amplitude = 35 deg. 3) Phi Amplitude = 20 deg. 4) Scan Center at Theta = 0 deg. and Phi = 0 deg. 5) Phase = 90 deg. Antenna motion defined an elipse about the center position.
10.	B70	Target Scan	1) Scan Center at Theta = 0 deg. and Phi = 0 deg. 2) Theta Scan Limit = 0 deg. 3) Psi Scan Limit = 70 deg. 4) Scan Velocity = 180 deg./s for both axes. This is a sector scan of 140 deg. total, along the horizon

TABLE 5.4-1: (Continued)

11.	STOW	STOW	
12.	B51	Target Sinewave	1) Scan Center at Theta = 10 deg. and Psi = 30 deg.. 2) Theta amplitude = 2.5 deg. 3) Psi amplitude = 2.5 deg. 4) Frequency = 2 Hz. 5) Phase = 90 deg. Conical scan about the target direction.
13.	B52	Target Sinewave	Same as 12 except centered about Theta = 10 deg and Psi = -30 deg..
14.	B53	Target Sinewave	Same as 12 except centered about Theta = 30 deg. and Psi = 10 deg..
15.	B54	Target Sinewave	Same as 12 except centered about Theta = 10 deg. and Psi = 0 deg., and amplitude of both axes increased to 5 deg..
16.	B55	Target Sinewave	Same as 15 except frequency increased to 4 Hz.
17.	B70	Target Scan	Horizon Scan. Same as 10 except the CVFF gain for feed forward velocity was set to 0.0.

A. Definition of Gimbal Axes:

1) First Axis (Nearest base)
   a) Also referred to as Y axis.
   b) Angle = Theta
   c) Loop number zero.

2. Second Axis (Nearest antenna).
   a) Also referred to as X axis.
   b) Angle = Phi.
   c) Loop number one.

B. Definition of Inertial (or Target) Axes.

1. Theta = angle above the horizon (elevation or pitch).

2. Psi = Azimuth angle from north.

represents the peak angle away from the center. For this run, peak to peak excursions would be 30 deg. for both axes. Scan velocity can be individually set for each axis, although in this case both were set to 45 deg. per second. Note that this is a box scan with the four corners located at the same points utilized in Test 2. However, here the cycling from point to point is accomplished automatically without intervention by the operator.

The Test 5 function, B44, is gimbal sinewaves into both axes although in this test the amplitude in one axis was set to zero. As indicated the frequency was 1 Hz and the scan center was about the antenna center position. Test 7, B45, put a sinewave with a 20 deg. amplitude into the other axis. In Test 9, B46, sinewaves were inserted into both axes with a phase angle between the two sinewaves of 90 deg.. With the differences in phase and amplitudes for the two sinewaves, the antenna was forced to define an elipse about the center position.

In the preceding tests the commanded functions and directions were always defined for gimbal angles. For the tests which follow target directions and function parameters are all defined with respect to the inertial reference frame, with appropriate transformations performed in the control software to define the commanded gimbal angles. This includes the complex "half angle" transformation required for directing the beam using a mirror. For all these tests the antenna alignment transformation was set as though the antenna center axis was pointing 45 deg. above the horizon. As indicated before, the

references systems are defined in Sections 2.2 and 2.3, and the functions in Section 2.5.

Test number 10, B70, is a target scan with the center of the scan direction north and on the horizon. Since the Theta scan limit was set to approximately zero the scan was a sector scan along the horizon. As indicated, scan velocity was 180 deg. per second. Test 12, B51, was a conical scan around the indicated center with a radius of 2.5 degrees. The target or center position was located at 10 degree elevation and 30 degree azimuth. Tests 13 and 14 were similar to 12 but about different target directions. Test 15 was the same as 12 except the conical scan was about a different target direction and the amplitudes of the sinewaves into both axes were increased to 5 degrees. Tests 16 was the same as Test 15 except that the rate for the conical scan was increased to 4 Hz.

The last test, Test 17, was a horizon scan. It was a duplicate of Test 10 except that the feed forward velocity gain was set to zero for this scan. With this condition, antenna transients at the turn around points were reduced making for a more quiet operation. However, as would be expected, angular error was significantly increased. Response curves presented in the following section illustrate this.

5.5 SYSTEM RESPONSES

Figure 5.5-1 shows the response of the first axis to a sinewave command. This was the only run presented in this report to be made in June, 1982. Other runs were made in September, 1982. This first run was included because it demonstrates some

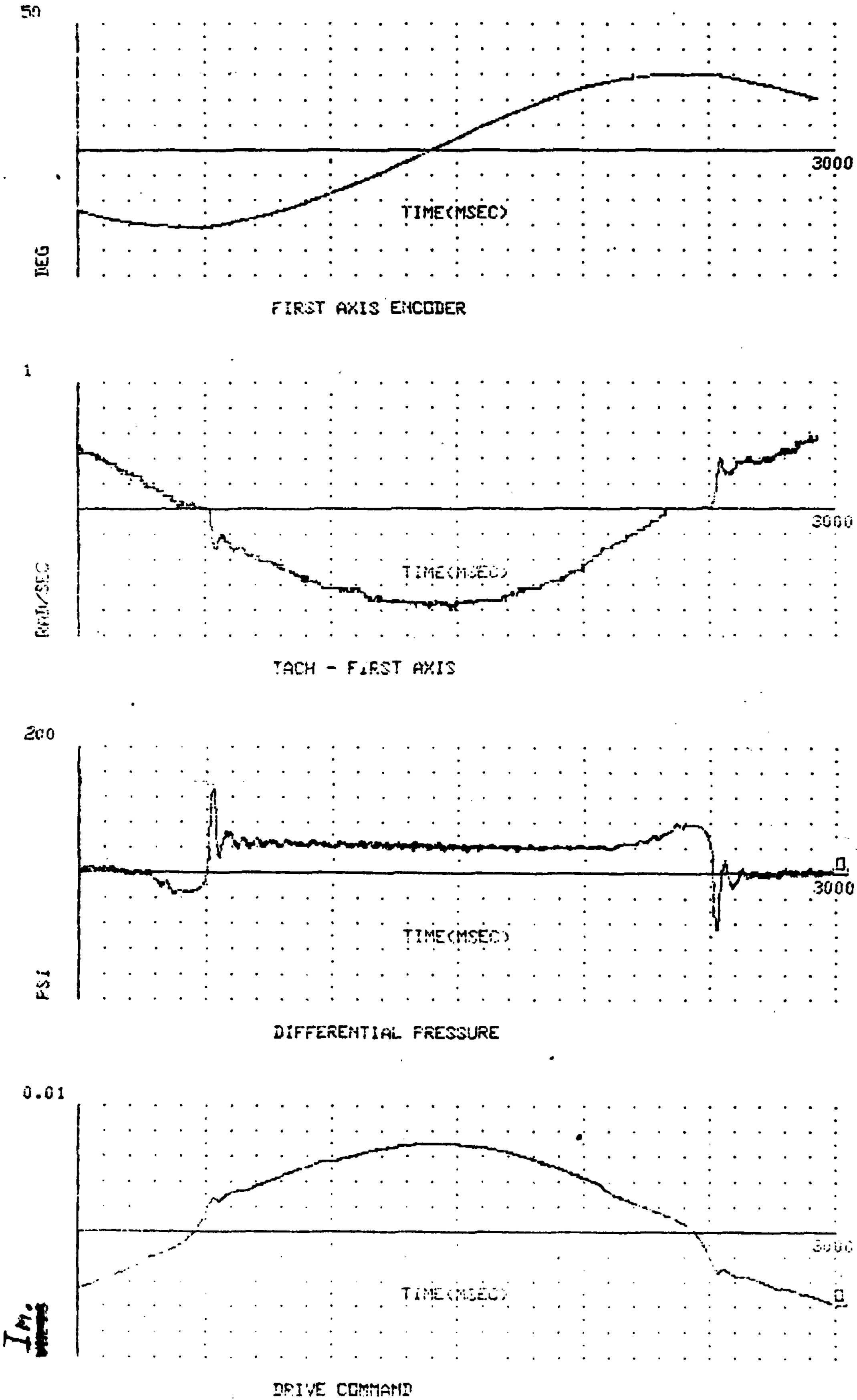
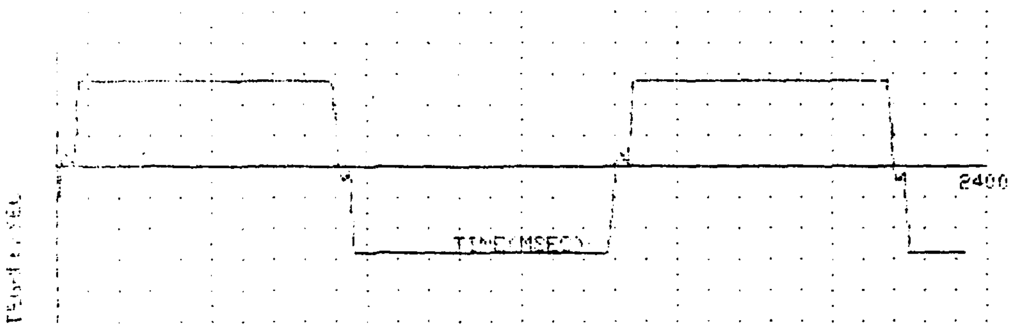


FIGURE 5.5-1: First Axis Sinewave Response (6/2/82)

of the idiosyncrasies present in the system. The deadband in velocity caused by friction is clearly visible on the run. Note that the differential pressure increases before the antenna actually stops. (It is assumed that the differential pressure should be centered about zero but problems with transducer drifts made centering difficult). The reason for pressure increasing prior to the gimbal stopping is not known. Perhaps it is due to one piston sticking while the other continued to move providing a resultant gimbal velocity. This would require flexure between the two piston mounts on the dish. However, the displacement angle due to flexure would be small for the run illustrated, since the gimbal angle changed very little near the area of the dead zone. The drive command, also shown, does not indicate a reason for the increase in differential pressure.

Figure 5.5-2 illustrates the system's velocity response to approximate 110 degree per second steps in velocity. The actual run here was a sector scan in the first axis. When the commanded scan velocity is reached it is held constant until the time to reverse direction. The commanded velocity is Y2 and the tach response is as illustrated. The tach measurement was obviously mis-scaled for this run since position feedback forces the gimbal velocity to be equal to Y2, at least averaged over short time periods. The run illustrates the fact that the velocity response is much more lightly damped near 0 degrees per second than when approaching higher rates.

Figure 5.5-3 shows the response to simultaneous sinewaves into the two axes. Here position errors (EP) for both axes are



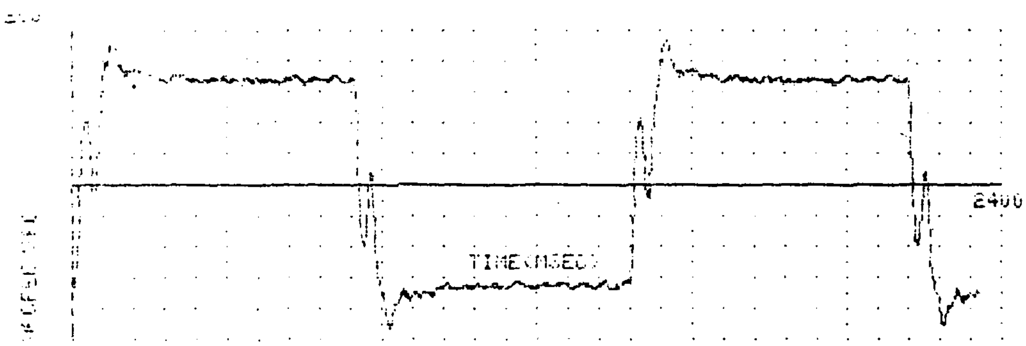


FIGURE 5.5-2

Velocity Response to Approximate 110 deg./s Steps
(Tach Scaling is in error.)

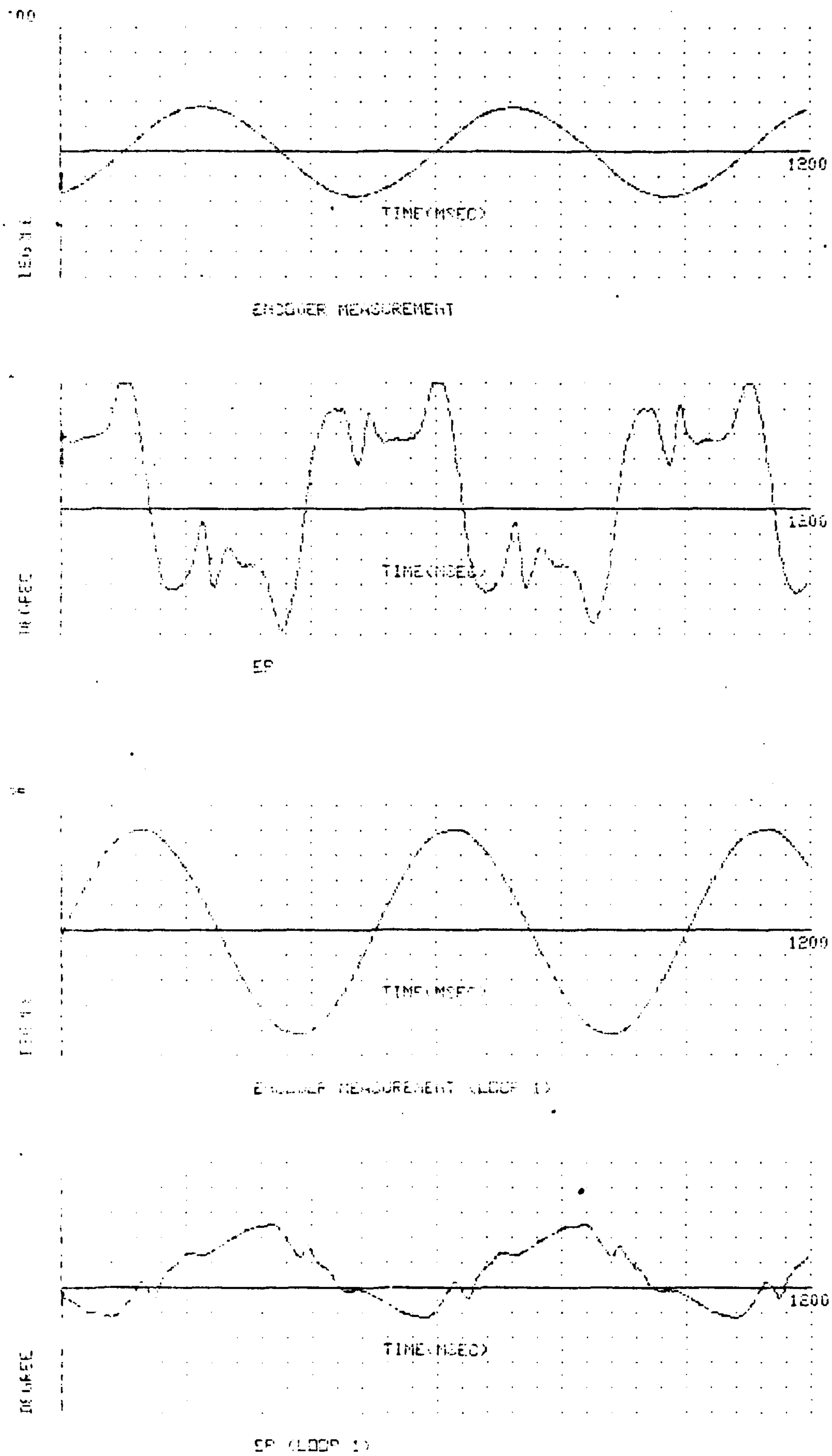


FIGURE 5.5-3: Simultaneous Sinewaves Into the 2 Axes

illustrated. The difference in the wave shape for the two error angles is not understood but may be due to cross feed between the two axes.

Figure 5.5-4 illustrates the horizontal scan response for the nominal position gain, Cp. For this run the feed forward velocity gain, CVFF, was set to zero. This run should be compared to Figure 5.5-5 which is similar except that the feed forward gain was set at the selected value. Note the considerable reduction in the average position errors in Figure 5.5-5 compared to Figure 5.5-4. However, the improvement at the turn around points was not as dramatic and the loop with CVFF equal to zero was quieter. For both of these two runs the velocity gain, C_V and the pressure feedback gain, CX3, were both set to zero. This was considered the nominal set of gains. Figure 5.5-6 illustrates the step response of the first axis with this set of gains.

Figure 5.5-7 illustrates the step response for the system utilizing differential pressure feedback, additional velocity damping, and higher position gain. Comparison of this run with the previous run shows not a lot of difference between the two except in the pressure measurement which was more lightly damped.

For the run of Figure 5.5-8 the velocity damping was decreased by using positive tach feedback. This reduced the response time of the system without significant overshoot. Since the set of gains on this run apparently improved system response, a recording was made of the systems horizontal scan response using the same set of gains. This is shown on Figure

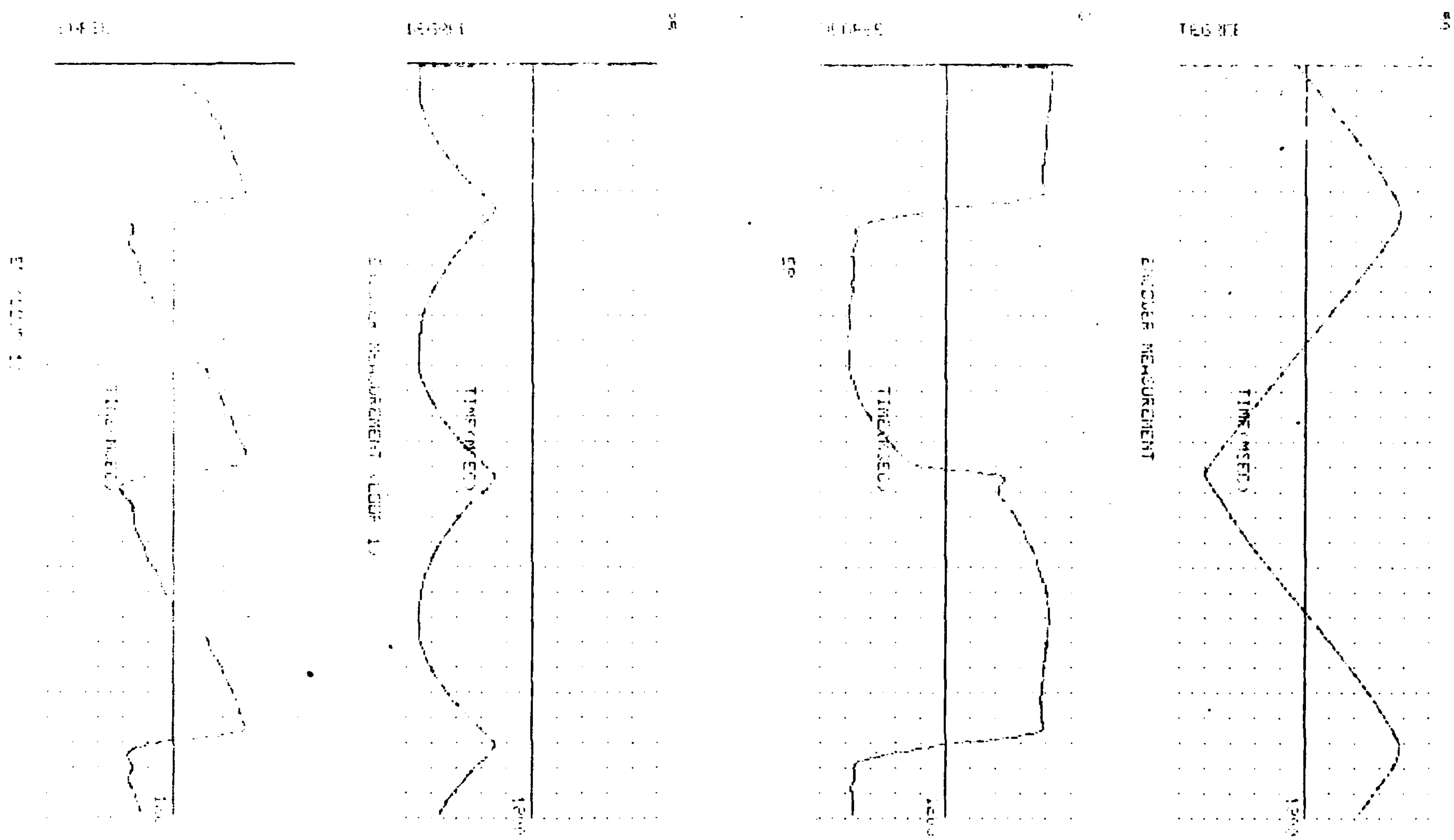


FIGURE 5.5-4: Horizontal Scan Response; $C_{VFF} = 0.0$; $C_p = 21.3$, $C_v = C_{\dot{x}3} = 0.0$

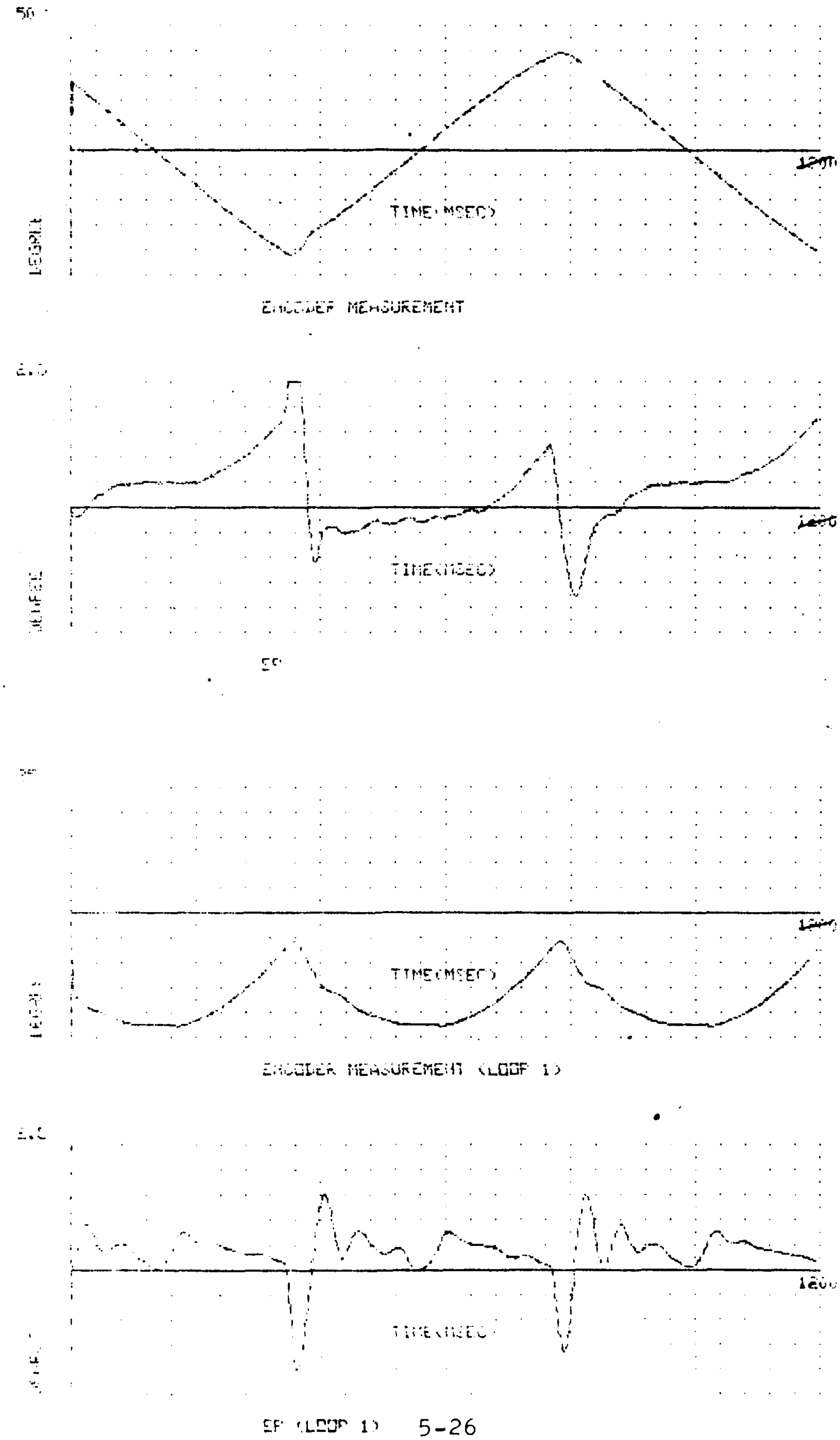


FIGURE 5.5-5: Horizontal Scan Response; $C_{VFF} = 1.05$, $C_p = 21.3$, $C_v = C_{x3}' = 0.0$

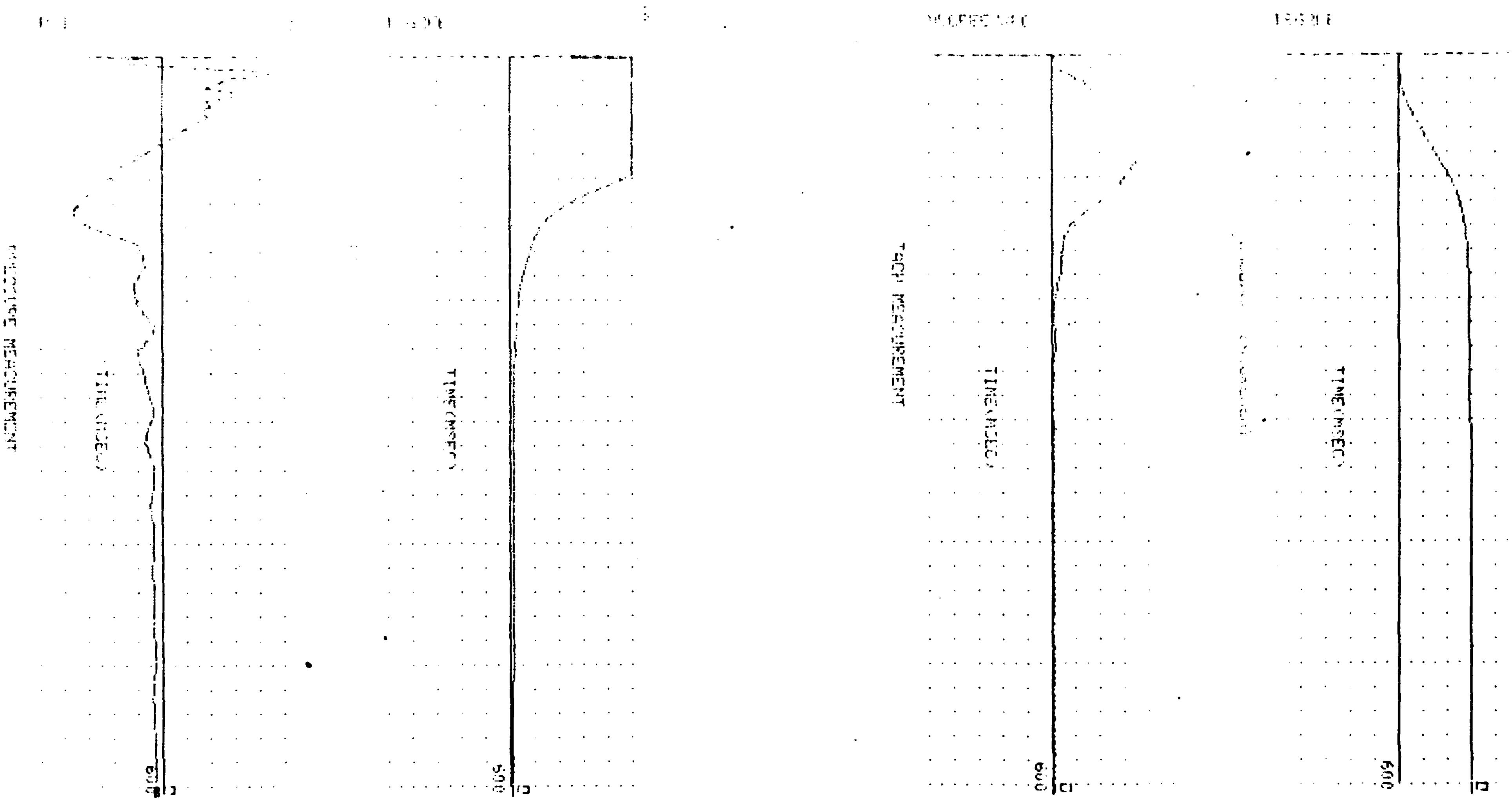


FIGURE 5.5-6: First Axis Step Response; $C_p = 21.3$, $C_v = C_{x3} = 0.0$

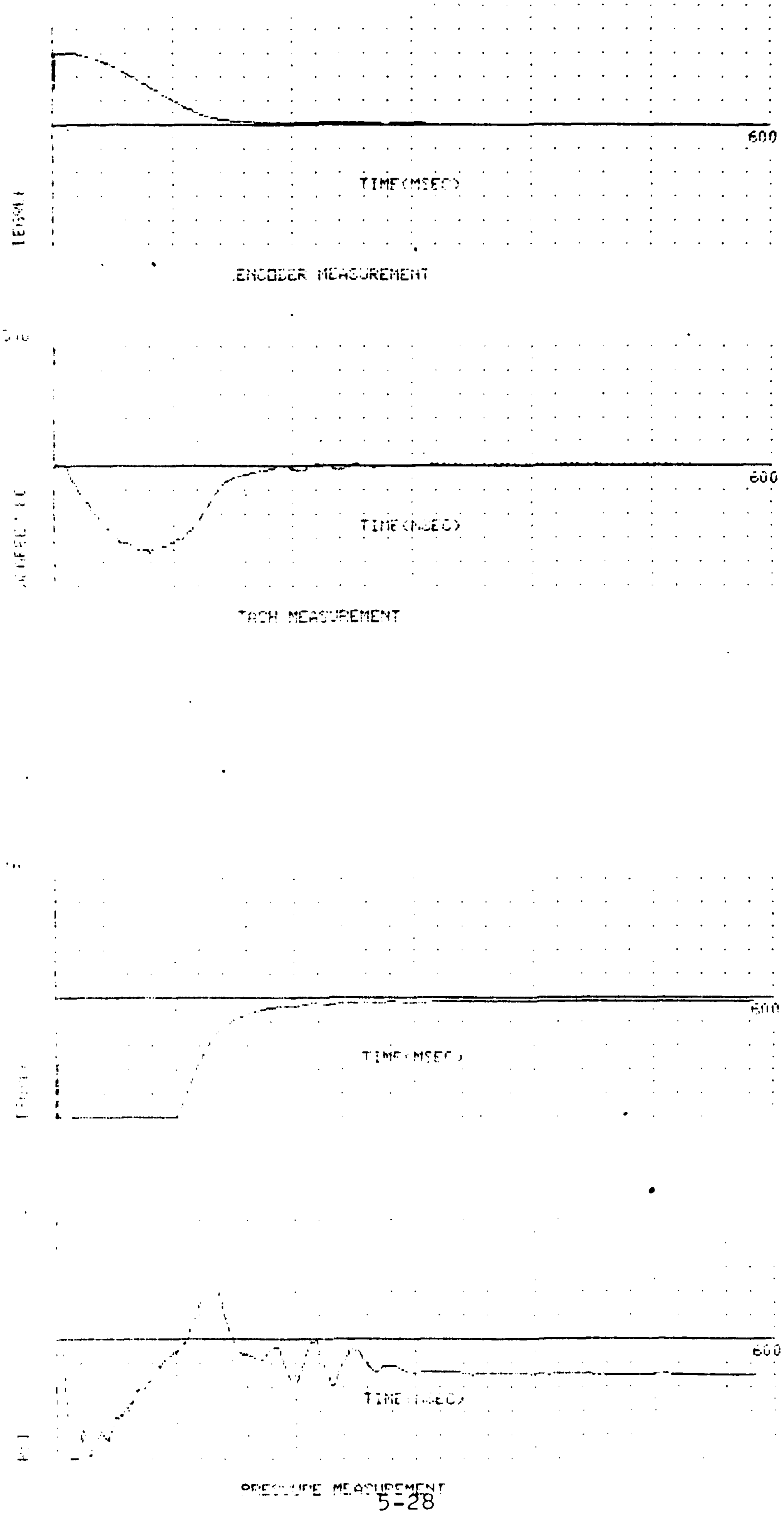


FIGURE 5.5-7: First Axis Step Response; C_p = 28.4, C_v = .0039, C_{x3} =-3.82

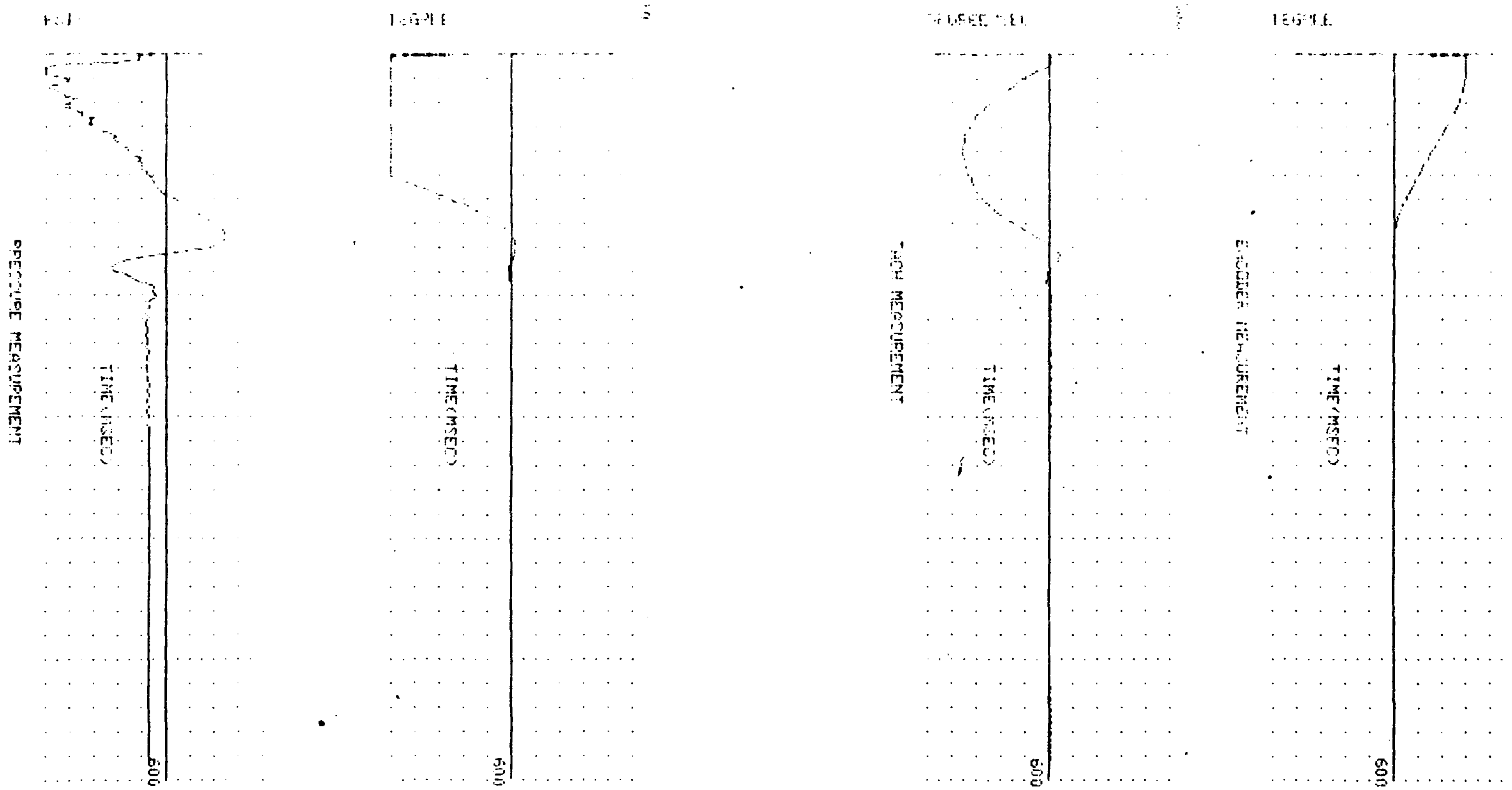


FIGURE 5.5-8: First Axis Step Response; $C_p = 21.3$, $C_v = -.0117$, $C_{x3} = -3.82$

5.5-9. A comparison of the position errors, EP, for this run and the run shown on Figure 5.5-5 does not show a dramatic improvement in position response. Note also on Figure 5.5-9 that a high frequency oscillation is present on the differential pressure measurement. This oscillation appears to be in the frequency range of 35 to 40 Hz. This oscillation was small in amplitude and could not be heard and caused no apparent problems. In general, oscillations, even small ones, are detrimental to system reliability and insufficient data was taken to determine under what conditions the oscillation could be made worse or better. Therefore, Navtrol recommends that this set of gains not be used until further investigation is completed.

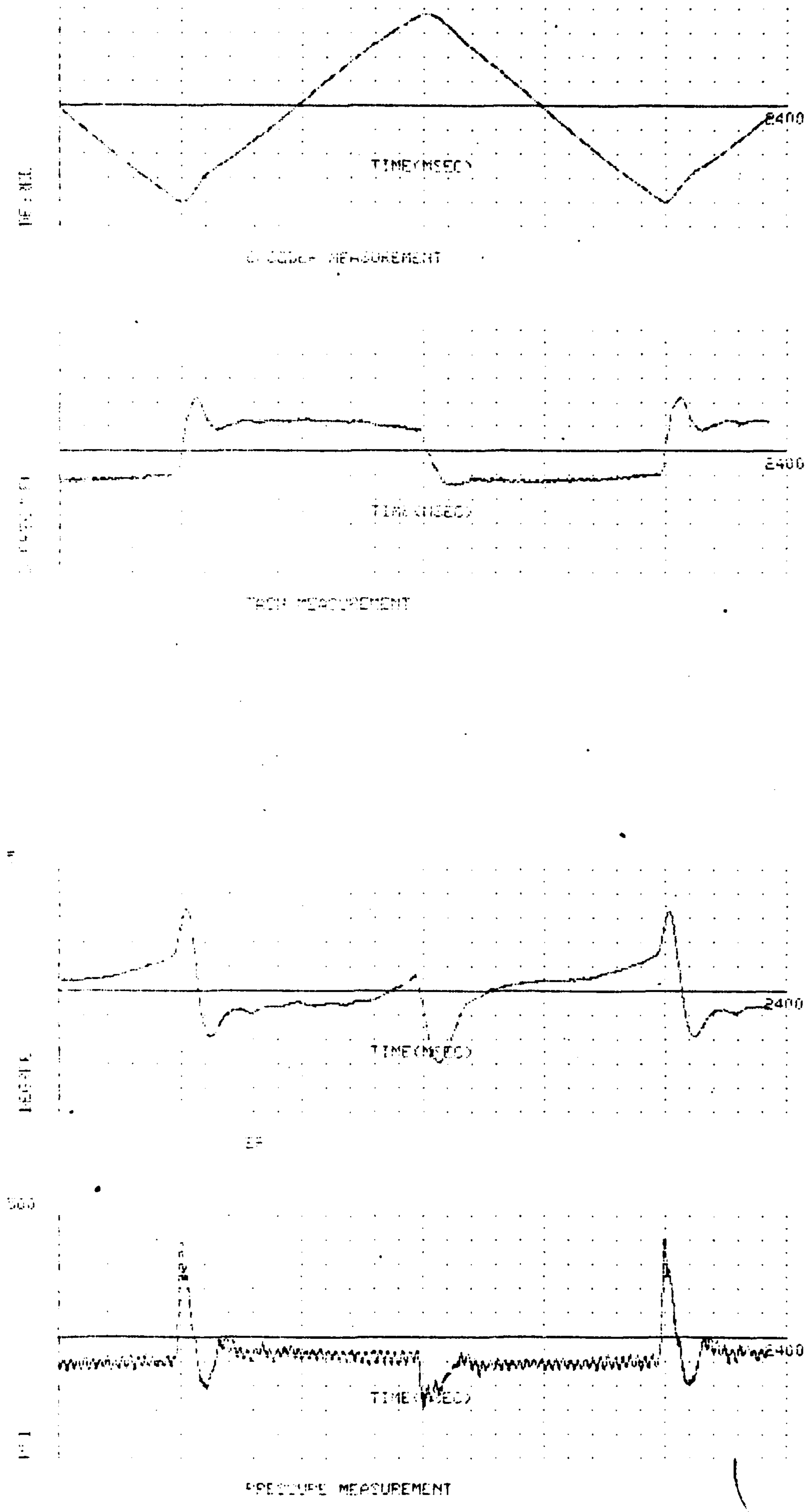


FIGURE 5.5-9: Horizontal Scan Response, $C_p = 21.3$, $C_v = -.0117$, $C_{x3} = -3.82$ (First Axis Only)

SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

(1) The principal conclusion is that a highly versatile and flexible digital control system has been developed for controlling the antenna for NRL's Directed Mirror Antenna Radar (DMAR). Integration with the antenna was successfully accomplished and system control performance should be more than adequate for use in testing the capabilities of the system for search and surveilance. Basic accomplishments of the program are listed on Table 6-1.

(2) The overall control system, including the mechanical structure and hydraulic system, appears to offer the potential of very high dynamic capabilities. Problem areas, discussed in (3) and (4), remain to be solved before the full potential can be realized.

(3) Certain structural members, particularly the hydraulic pistons and their connection points to the mirror, require mechanical stiffening to reduce vibrations encountered when the system is operating at high rates and high accelerations. It is probable that the addition of the RF "reflecting" material dampened the vibration somewhat but measurements have not been made since this occurred. Even so, it is reasonably certain that several areas could benefit from re-design or re-fabrication, drawing on experience gained with the present design.

(4) Friction within the system is excessive and not well

TABLE 6-1: PROGRAM ACCOMPLISHMENTS

A. Initial Program:

1. Fabricated and delivered "All Dgital Controller" (ADC).
2. Designed, developed, fabricated and delivered 2 Interface Units to interface ADC with hydraulic system.
3. Defined special algorithms for mirror control.
4. Wrote initial software program providing antenna control.
5. Successfully integrated system at NRL.

B. Follow-on Program

1. Re-organized and greatly expanded software program for antenna control. Added sinewave, scan and track functions about 8 targets or 8 sets of gimbal angles.
2. Designed, and developed a serial communication board to allow communication between two ADC Processor Units. (This was for use with 3.)
3. Developed hydraulic system simulation (real time) in an ADC Processor Unit and for use in testing NRL system software at Navtrol.
4. Developed in the FP Computer a file capability for storing parameters on as many as 40 response curves, greatly simplifying and speeding up the plotting of system responses. Improved the menu prompting for calling of functions and defining the sets of gimbal or target direction angles.
5. Successfully demonstrated system and software at NRL.
6. System is now considered ready for RF system installation and tests.

behaved. It appears to contribute to the vibration which has been observed. It is possible that stiffening the mechanical structure will improve the frictional behavior. In addition, stiffening might allow higher feedback gains to be used, decreasing the effect of friction.

(5) The system could very well profit by additional time spent on the optimization of system gains and circuitry. Several design features were not adequately tested. For example, analog feedback of differential pressure was provided for but never adequately tested. This is also true of the somewhat novel approach for extending the apparent bandwidth for the hydraulic valve. Whether the mechanical improvements should be accomplished prior to additional optimization has not been determined.

(6) At present, computation required for control of the DMAR antenna requires only a portion of available memory and a little more than two-thirds of the time available. This is true in spite of the fact that the computer calculates 512 times per second both displacement and rate transformations for ships motion, antenna alignment and the complex "half angle" transformation required for directing a beam using a mirror. Computation also includes the control algorithms, the integration of 8 targets, and algorithms for box or conical scans. The program has not been optimized for timing and it is estimated that with optimization the time utilization could be reduced to approximately 50% of the total time.

(7) Two much of the ADC Processor Unit time is set aside

for transfering information between the All Digital Controller and the Front Panel or other computer. This is because the present parallel interface does not provide for storage of multiple words. (The discussion on processor time utilization in (6) does not take into account the time required for passing this information.)

(8) A novel approach for defining the control of a mirror and directing a beam towards a target was developed, implemented and demonstrated on this program.

6.2 RECOMMENDATIONS

(1) Develop Parallel Interface With PDP-11 Computer.

Navtrol has previously developed the capability for transferring information in parallel between a PDP-11 computer and the All Digital Controller System. NRL requires this capability to facilitate testing of the overall DMAR System. One interface has been fabricated and tested, and it can be duplicated although it utilized wire wrap circuitry and fabrication details are not completely defined. Navtrol has also developed Fortran callable sub-routines for the PDP-11 which no doubt can be utilized. These routines could probably be adapted for the present application and made available to the Navy.

(2) Develop Parallel I/O Board With Storage Capability.

The present Parallel IO board used in the All Digital Controller System has no multiple word storage capacity. The transfer is made one word at a time and this requires excessive time for the All Digital Controller away from its control responsibilities. If 16 or more words could be stored these could be transferred all at once into ADC memory. In addition,

the PDP-11 would have almost the entire sampling period for loading or reading the data being transferred.

(3) Optimize Control and Control Inputs.

It appears probable that control could be improved by full uitiliztion of some of the features designed into NRL's Digital Controller System. Whether this control optimization should be delayed until certain structural problems are corrected (see Recommendation 4) is not known. It also appears that the routine for the box scan could be modified to reduce the turn around transients. This last task is relatively minor but one which may reduce wear and tear on the control system.

(4) Correct Mechanical Problems

The hydraulic pistons and their connection points to the mirror require mechanical stiffening to reduce vibrations. In addition, friction is high and not well behaved adding to the vibration problems and increasing control errors.

(5) Optimize Program Timing.

By integrating the serial I/O routines better into the program, replacing certain double precision routines with single precision ones and making other software refinements, it is expected that the timing required for the control program could be reduced considerably. At present there is adequate time for control but if additional functions, such as are recommended in (6), were made program timing could become critical.

(6) Implement "Reverse Tranformation" of Gimbal Angles.

At present the control inputs are defined in the inertial reference frame and transformed through ship's transformation,

antenna alignment transformation, and the "half angle" transformation required to define gimbal angles in turn required to place the beam on the target. If the gimbal angles could be made to perfectly follow commanded gimbal angles, the beam would precisely point in the commanded direction. Then, the commanded direction could be fed directly to PPI scopes or other displays. However, dynamic constraints prevent this from ever being completely accomplished. What is needed for PPI scopes or other displays is the actual direction that the beam is pointing. This can be defined by the gimbal angles or by the combination of commanded direction plus gimbal angle error. Either the gimbal angles or the error would have to be transformed from the antenna back into the inertial reference frame to provide the appropriate information. Note that this reverse transformation also includes a reverse "half angle" transformation.

(7) Implement a Capability for Multi Target Track.

The original concept for the DMAR radar was to scan through as many as 7 targets, never completely stopping and performing this scan in minimum time while satisfying the constraint for beam dwell time on each target. Partial implementation of this approach could be easily accomplished by letting the operator select the order in which the targets are accessed and having the beam stop at each target for a short pre-set time period. Optimum traveling from target to target automatically, without intervention from the operator, is a much more complex problem but one Navtrol would like to tackle.

(8) Implement Optimum Control Techniques.

Navtrol has developed on one of its "in house" computers a

simulation of the hydraulic control system used in controlling the DMAR antenna. This program needs some refinement but could be used within the control computer to provide additional feedback parameters such that higher gain and better antenna control could result. Measurements would be used to correct the modeled system. The model with the correction gains represents a constant gain "Kalman Filter" used for optimum estimation of hydraulic system parameters not available for measurement. This approach has been successfully utilized by Navtrol in several applications.

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